

Reduction of Undesired Range Shifting in an Agricultural Continuously Variable Transmission

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Abstract

The subject of this thesis was to investigate the possibility of a supplemental control algorithm to suppress gear alternation in the ZF ECCOM gearbox series. The acquired solutions were implemented on a dSpace MicroAutoBox II and connected to a Claas Xerion 5000 to evaluate their effect. The different approaches have gone through three steps of validation, first a Simulink model simulation, secondly a tractor simulator test, and finally tests on the real tractor.

Keywords: dSpace MicroAutoBox II, ECCOM gearbox, CVT, continuously variable transmission, gear hunting, gear alternation, range shifting, CANape, CANalyzer, droop limit, ZF Friedrichshafen AG, driveline, powertrain, VDC, ECU, TCU, vehicle CAN-buses, Simulink.

Contents

1	Introduction	1
1.1	The company	1
1.2	Problem description	1
1.3	Goal of the thesis	2
1.3.1	Subtasks	2
1.4	Limitations	3
1.5	Outline of thesis	3
1.5.1	Notes to the reader	4
1.6	Material	4
1.6.1	Software	4
1.6.2	Hardware	5
1.7	Individual contribution	5
2	System description	7
2.1	Powertrain	7
2.2	Diesel engine	9
2.2.1	Performance	9
2.2.2	Fuel consumption	9
2.3	Transmission	10
2.3.1	Shifting drum	11
2.3.2	Hydrostatic unit	12
2.4	Advantages of CVTs	12
2.5	Vehicle control units	14
2.6	Connection overview	15
2.7	Droop limit	15
3	Analysis	19
3.1	Gear alternation	19
3.2	Gearbox efficiency	20
3.2.1	Gear efficiency effect - needed rpm	24
4	Method description	27
4.1	Hardware and software description	27
4.1.1	Test environments	27

4.1.2	MicroAutoBox II	28
4.1.3	Data collection	28
4.1.4	CANalyzer	29
4.1.5	CANape	29
4.2	Setup	32
4.3	Possible approaches	32
4.3.1	Droop limit adjustments	33
4.3.2	Range shift limitation	35
4.3.3	Torque limitation	35
4.3.4	Load dependent solutions	36
5	Implementation	41
5.1	Simulink model of the VDC	41
5.1.1	Simulink block descriptions	41
5.2	MicroAutoBox II	42
5.2.1	Communication	43
5.2.2	Approaches	44
6	Simulink model tuning	51
7	Result and observations	55
7.1	Simulink	55
7.1.1	Fixed adjustment of the droop limit	55
7.1.2	Pole sliding adjustment	55
7.1.3	Integral adjustment	55
7.2	Tractor simulator	58
7.2.1	Comparison increased/decreased droop limit	58
7.2.2	Range shift limitation	59
7.2.3	Torque limitation	59
7.3	Tests on Xerion 5000	60
7.3.1	Positive or negative adjustment of the droop limit	60
7.3.2	Pole adjustment	60
7.3.3	Range shift limitation	60
7.3.4	Engine load drop	62
8	Conclusions	67
8.1	Droop limit adjustment	67
8.2	Range shift limitation	67
8.3	Torque limitation	67
9	Future work	69
A	A short guide to MicroAutoBox II	71
A.1	Introduction	71
A.2	Connecting the hardware	72
A.3	Creating a Simulink model	74
A.4	Downloading a Simulink model to MicroAutoBox II	76

<i>CONTENTS</i>	iii
A.5 Using CANalyzer and CANape	78
A.5.1 CANalyzer	79
A.5.2 CANape	79
A.6 XCP on Ethernet	81
A.7 Comments	82
B Enlarged figures	85
B.1 Simulink	85
B.2 Large figures	92
C Logbook from test runs on Xerion 5000	99
D CAN message table	103
D.1 Created CAN messages	103
D.2 Used CAN messages	103
D.3 Description of the signals in the CAN messages	103
D.4 Table of the signals used in the CAN messages	104

List of Figures

1	<i>AEPT</i> and <i>PLACS</i> in the engine torque curve	x
1.1	ZF ECCOM 4.5 CVT	1
1.2	Claas Xerion 5000	2
2.1	Cross-section view of a tractor	8
2.2	Engine performance - kW, hp and Nm per <i>rpm</i>	9
2.3	BSFC - Engine efficiency	10
2.4	The torque flow of the CVT.	10
2.5	ECCOM interior view	11
2.6	Shifting drum interior view	12
2.7	Planetary gear set	12
2.8	Hydrostatic unit	13
2.9	Hydrostatic unit - connection to the gearbox	13
2.10	Process overview	15
2.11	CAN bus overview	16
2.12	The droop limit effect on the engine <i>rpm</i>	17
3.1	Gear alternation during field drive.	20
3.2	Efficiency chart of the ECCOM 1.8	21
3.3	Simulink model of the load controller	22
3.4	<i>Rpm</i> during efficiency run	23
3.5	<i>TRR</i> during efficiency run	23
3.6	<i>TRR</i> - Hydrostatic direction swaps and gear change marked	24
3.7	The load during the run	26
3.8	The load during run - zoomed active area	26
4.1	MicroAutoBox II	28
4.2	CANcaseXL	28
4.3	CANalyzer overview	29
4.4	CANalyzer IG	30
4.5	CANalyzer Trace	30
4.6	CANape	31
4.7	Comparison of different droop limit adjustments	33
4.8	Droop limit adjustment using the pole method	35

4.9	The pole adjustment's influence on the whole system	36
4.10	Droop limit adjustment using the log method	37
4.11	<i>RSL</i> effect	38
4.12	<i>RSL</i> effect on the whole system	39
4.13	Torque limitation	40
5.1	The I-adaptive block	42
5.2	Velocity controller	42
5.3	Droop limit controller	43
5.4	The I/O of the program on the MAB.	44
5.5	Fixed droop limit adjustment	45
5.6	Linear droop limit adjustment	46
5.7	Pole and logarithmic droop limit adjustment	47
5.8	<i>RSL</i> approach	48
5.9	Engine limitation approach	49
6.1	Plot of the critical region. Low gained controller.	51
6.2	Plot of the critical region. Full gained controller.	52
6.3	Full gained controller. Single gain scheduling.	52
6.4	Full gained controller. Dual gain scheduling.	53
7.1	Critical region with fixed negative droop adjustment	56
7.2	Critical region with fixed positive droop adjustment	56
7.3	Critical region with pole adjustment	57
7.4	Critical region with integral adjustment	57
7.5	Gear alteration in relation to load	58
7.6	<i>RSL</i> effect in tractor simulator.	59
7.7	Pole adjustment effect on the real tractor	61
7.8	<i>RSL</i> effect on the real tractor	62
7.9	<i>DTRR</i> limitation effect on <i>TRR</i>	64
7.10	<i>PLACS</i> drop during test runs	64
7.11	<i>RSL</i> effect on the <i>PLACS</i> drop	65
7.12	Pole adjustment effect on the <i>PLACS</i> drop	66
A.1	Settings for the internet protocol	73
A.2	Desired answer when pinging the MicroAutoBox II.	73
A.3	The library for Real-Time Workshop.	74
A.4	Blocks for utilizing RTI on CAN	75
A.5	RTI CAN receive message	77
A.6	Connection dialog - MAB and computer	78
A.7	Settings for the Real-Time Workshop build process.	78
A.8	Blocks for utilizing RTI on Ethernet	81
B.1	Enlargement of Figure 5.1	86
B.2	Enlargement of Figure 5.2	87
B.3	Enlargement of Figure 5.3	88

LIST OF FIGURES

vii

B.4	Enlargement of Figure 3.3	89
B.5	Enlargement of the MAB program	90
B.6	Enlargement of the MAB program	91
B.7	Enlargement of Figure 3.6	93
B.8	Enlargement of Figure 2.12	94
B.9	Enlargement of Figure 4.7	95
B.10	Enlargement of Figure 2.10	96
B.11	Enlargement of Figure 3.1	97

Notation

Acronyms and abbreviation

- *AEPT* - Actual engine percentage torque, i.e. how many percent of the possible torque that is currently used, see Figure 1.
- BSFC - Brake Specific Fuel Consumption.
- Critical region - Refers to the region where gear alternation may occur.
- CVT - Continuously variable transmission.
- DOF - Degrees of freedom.
- *DTRR* - Desired Transmission Reciprocal Ratio, the wanted gear ratio.
- ECU - Engine Control Unit.
- MAB - MicroAutoBox II.
- *PLACS* - Percentage load at current speed, i.e. how many percent of the possible torque output at the current *rpm* that is used, see Figure 1. This is valid during normal operation e.g. no smoke limitations¹.
- PTO - Power take-off unit. An outlet used to connect implements to the agriculture vehicle.
- PWM - Pulse-width modulation.
- *rpm* - Revolutions per minute.
- *RSL* - Range shift limitation.
- *RSSL* - Requested speed / speed limit.
- TCU - Transmission Control Unit.
- *TISS* - Transmission input shaft speed.
- *TOSS* - Transmission output shaft speed.
- *TRR* - Transmission Reciprocal Ratio, the current gear ratio. Same as the variable i_G .
- VDC - Vehicle Drivetrain Control unit.
- ZF - Zahnradfabrik, "gear factory".

¹Smoke limitation exist to prevent bad exhaust values.

Variables used

- η - The efficiency.
- η_{loss} - The efficiency difference between two gears.
- τ_{in}/τ_{eng} and τ_{out} - Torque in/eng from the engine and torque out from the gearbox [torque Nm].
- τ_{need} - The needed torque to handle the efficiency loss between the gears.
- $E(i_G)$ - Function that returns the efficiency at the given i_G .
- i_{diff} - Differential ratio.
- i_G - Current gear ratio. Same as the acronym *TRR*.
- i_H - The gear with the higher efficiency.
- i_L - The gear with the lower efficiency.
- i_{PTO} - The fixed *PTO* ratio.
- l_{tire} - Tire circumference.
- n_{change} - The size of the needed *rpm* change to handle efficiency loss between gears.
- n_{dim} - The droop limit value.
- n_{eng} - Current motor *rpm*.
- n_{need} - The needed *rpm* for a given torque.
- n_{out} - Shaft velocity out from the gearbox.
- P_{eng} - Power from the engine to the input of gearbox.
- P_{out} - Power out from the gearbox.
- $R(torque)$ - Function that returns the *rpm* needed to acquire the given torque.
- $T(rpm)$ - Function that returns the engine torque at the given *rpm*.

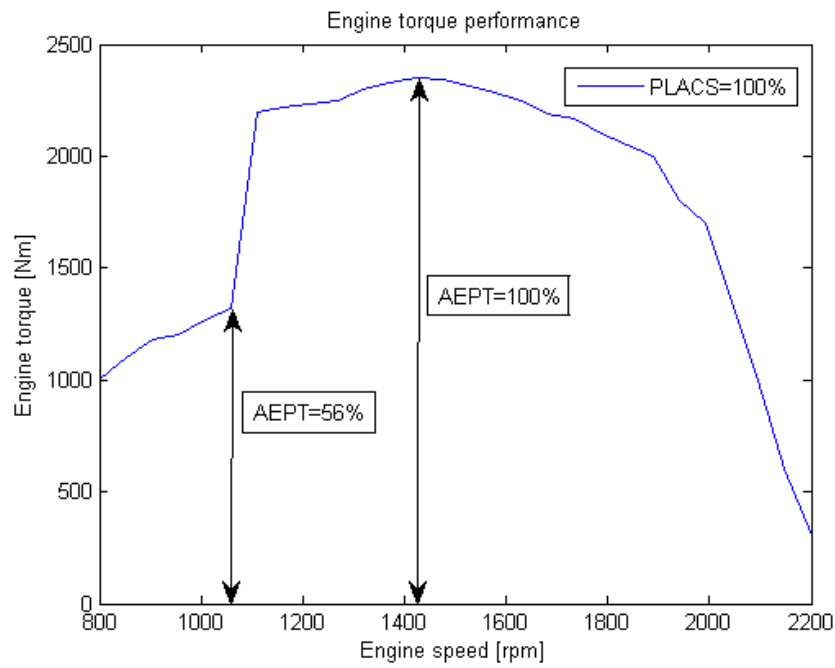


Figure 1: PLACS is one along the torque curve, while the AEPT is only 1 at the torque peak.

Chapter 1

Introduction

1.1 The company

This thesis work was performed at the company ZF Friedrichshafen AG. With more than 70.000 employees worldwide ZF is one of the largest manufacturers of parts for the automotive industry. Their product line consists of transmissions, steering systems, axle components and much more.

1.2 Problem description

In this thesis a problem that occurs in some powertrain strategies was investigated. A simplified control strategy¹ for the ZF ECCOM² gearbox series was used and it could be forced into this problem. The gearbox used during the tests was the ECCOM 4.5 continuously variable transmission. This gearbox is a part of the tractor Claas Xerion 5000 that is used in agricultural work with the possibility to attach various implements. The ECCOM 4.5 can be seen in Figure 1.1 and the Xerion 5000 can be seen in Figure 1.2. During certain situations when an inexperienced driver choses to drive with a badly chosen droop limit³ the gearbox may start alternat-

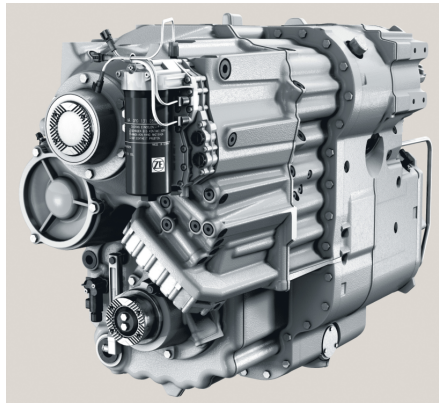


Figure 1.1: ZF ECCOM 4.5 CVT [7]

¹Control strategy is the by manufacturer implemented program controlling the powertrain in the vehicle.

²See section 2.3 for more information regarding the ECCOM gearbox.

³This is a rpm limit set by the driver. For further information about droop limit see Section 2.7

ing between the second and third gear. This happens while the tractor is exposed to heavy loads due to the usage of implements such as a plow or a cultivator. This means that the problem only occurs if the droop limit and the load of the vehicle are poorly combined while the velocity reference is higher than what the tractor currently can reach. Under these conditions the gearbox alternates between the second and third gear until either the load is changed or the droop limit has been altered. This effect is undesired since it wears out the clutches of the gearbox and creates noise as well as small jerks.



Figure 1.2: Claas Xerion 5000 [8]

1.3 Goal of the thesis

The goal of the thesis is to find out how a simple modification of the current strategy could be implemented to prevent gear alternation. If a small modification was possible it should be implemented as a supplemental control algorithm to the existing powertrain strategy and then tested on the real tractor. It is considered a plus if the solution is implementable in the TCU⁴ software. The reason for this is that it would be able to work with different strategies, i.e. strategies that are not developed by ZF.

1.3.1 Subtasks

To solve this a few subtasks were defined in order to complete the main goal:

⁴For further information about the TCU, transmission control unit, see Figure 2.5.

- Create a working Simulink model of the VDC⁵ that can be forced into gear alternation.
- Implement the solution on the MAB, MicroAutoBox II⁶, tune it in the tractor simulator as well as for the real tractor.
- Write a simple manual for MAB.

1.4 Limitations

The possible solution may not make any large alterations to the current VDC. It should neither be noticeable by the driver nor should driving options in the current strategy be altered. Finally, the solution should be small and efficient to save on the calculation power needed.

1.5 Outline of thesis

Since this thesis requires a broad spectrum of background knowledge Chapter 2 takes up a large portion of the report. In addition to this, several appendices have been added for even more insight in the project. This is done so that the reader may get involved and have adequate background knowledge to be able to follow the line of thought behind the solutions. The different parts of the thesis are divided into the following chapters:

- *System description* contains the necessary background information to understand the system investigated in this thesis.
- *Analysis* investigates the characteristics of the system.
- *Method description* explains the problem setup as well as the line of work.
- *Implementation* shows the implementations made in Simulink.
- *Simulink model tuning* goes through the tuning made to the Simulink model.
- *Result and observations* present the results of Simulink runs, tractor simulations as well as tractor runs.
- *Conclusion* summarizes the outcome of the thesis.
- *Appendix* is composed of the guide how to setup and use MAB, large figures of the Simulink models, the unaltered logbook from the test drives on the Xerion 5000 and a CAN message table used in the connection setup between the VDC and the MAB.

⁵For further information about the VDC, vehicle control unit, see Figure 2.5

⁶Further information regarding the MAB can be seen in Section 4.1.2.

1.5.1 Notes to the reader

- The reader should notice that the testing of a solution consists of three steps:
 1. Tests and development of the Simulink model.
 2. Implementation on the MicroAutoBox II and then tests on the tractor simulator⁷.
 3. Final testing and tuning on the real tractor.
- The reader should also notice that most of the Simulink models that are included in the report can be seen in large versions in Appendix B.
- Throughout the report the expression gear is used but the reader should know that in a continuously variable transmission there are no fixed gears, only ranges. This means that when the expression gear shift/change is used it refers to a shift between the ranges.
- The gear ratios mentioned in this report are not the traditional gear ratios, they are instead reciprocal ratios. The traditional gear ratio is defined as $ratio = \frac{n_{eng}}{n_{out}}$ while the reciprocal ratio is defined as $reciprocal\ ratio = \frac{1}{ratio} = \frac{n_{out}}{n_{eng}}$. The reason for this is that in computer systems it is not possible to represent the $ratio = \infty$, but with reciprocal ratio the ratio goes towards zero rather than ∞ .

1.6 Material

1.6.1 Software

- Mathworks Matlab.
- Matlab licenses for Simulink, Real-Time workshop, and Stateflow.
- dSpace TargetLink.
- Vector CANape.
- Vector CANalyzer.
- A Simulink model representing the engine and gearbox, without the VDC implemented.

⁷The tractor simulator is a so called hardware in loop simulator, i.e. a simulator connected to the real control systems such as the VDC, TCU and ECU

1.6.2 Hardware

- dSpace MicroAutoBox II, see Figure 4.1.
- Claas Xerion 5000, see Figure 1.2.
- ZF ECCOM 4.5 CVT, see Figure 1.1.
- Access to a tractor simulator, a so called hardware in loop simulator.

1.7 Individual contribution

During the first month the work was divided into two parts. The first part was setting up the communication and learning the programs used with the MicroAutoBox II, this was done by Henrik. The second part was creating the Simulink model of the VDC and acquire the background knowledge of the process, this was done by Michael. In general Michael has put more time in the Simulink simulation while Henrik has put more time with the tractor simulator. Apart from this no specific division was performed.

Chapter 2

System description

2.1 Powertrain

The powertrain are the parts of a vehicle that generates power, transfers it and converts it into motion, see Figure 2.1. The powertrain in a tractor using components from ZF consist of the following parts [1]:

- An engine which generates the power to move the vehicle.
- A u-joint drive shaft that transfers the power from the engine to the transmission.
- A transmission that adapts the torque and *rpm* from the engine to the current driving situation.
- A differential that diverts the power from the transmission to the wheels.

The engine *rpm* is proportional to the fuel injection, which is determined by the position of the driving pedal and the driving strategy. Equation 2.1 shows the relation between the vehicle velocity and the powertrain variables. From this equation it can be seen that the system has two degrees of freedom, DOF, engine speed and gear ratio.

$$Velocity = n_{eng} \cdot i_G \cdot i_{diff} \cdot l_{tire} \cdot 3.6 \quad (2.1)$$

Where:

- n_{eng} *rpm* [min^{-1}] - Engine output *rpm*.
- i_G [*no unit*] - Current gearbox ratio.
- i_{diff} [*no unit*] - Fixed differential ratio.
- l_{tire} [m] - Tire circumference.
- 3.6 [*factor* $\frac{m}{s} \rightarrow \frac{km}{h}$] - Conversion between meter per second and kilometers per hour.

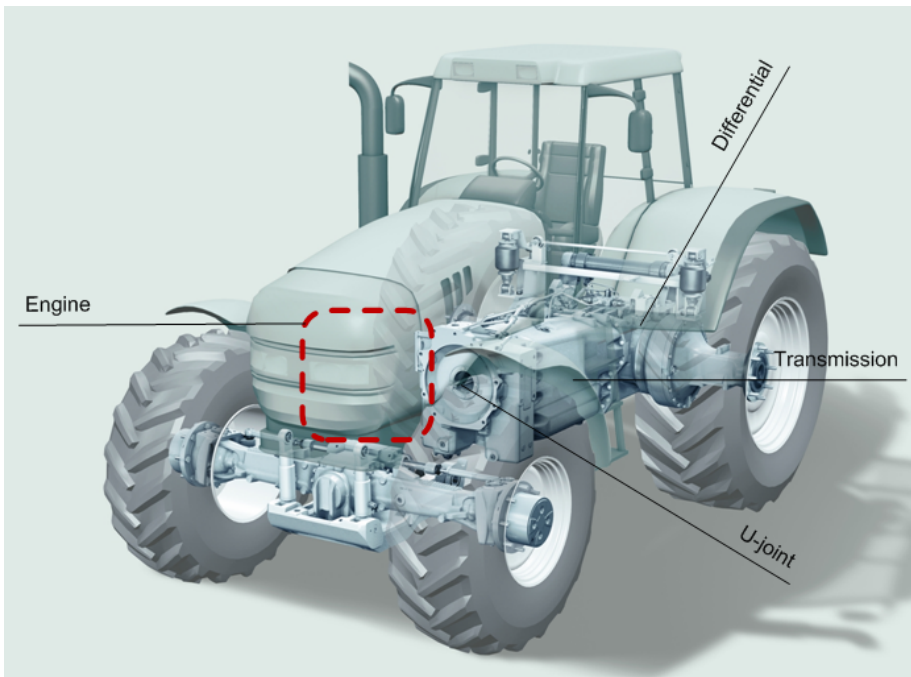


Figure 2.1: Powertrain for a tractor with a ZF CVT [6]

2.2 Diesel engine

The engine installed in the Xerion 5000 is a Caterpillar, 6-cylinder, 12.5L, which has a maximum torque of 2350 Nm at 1400 *rpm* and a power peak of 385kW at 1800 *rpm*. The torque peak is the point where the engine delivers the largest torque and the power peak is the point where the product of the torque and the speed is the highest. The power peak is also the point where the vehicle can handle the largest load at the highest possible speed.

2.2.1 Performance

The engine performance during different driving situations is crucial and must be taken into account when designing solutions effecting the engine *rpm*. In Figure 2.2 the torque and power depending on the *rpm* can be seen.

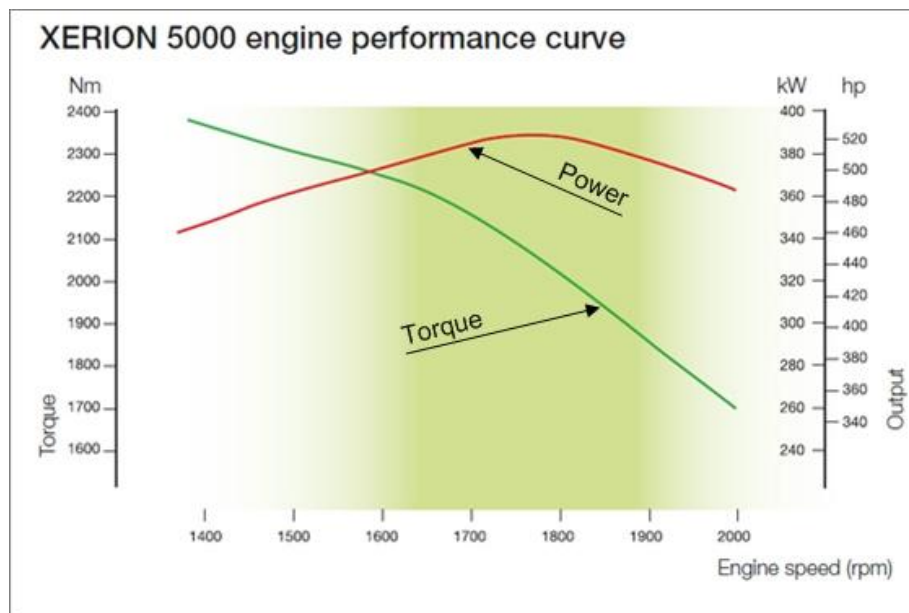


Figure 2.2: Engine performance [8].

2.2.2 Fuel consumption

When the *rpm* reference to the engine is being calculated the brake specific fuel consumption, BSFC, curve is a good tool to work with. From this curve regions where fuel consumption is unnecessarily high may be identified and avoided. The BSFC can be seen in Figure 2.3. A quick analysis shows that an engine under load is better the one that is only working in the midrange. This is why it is favorable to have a driveline strategy that keeps the *rpm* low when the vehicle load is small which lowers the fuel consumption. When the load is larger the strategy keeps the *rpm* high to be able to satisfy the driver demands.

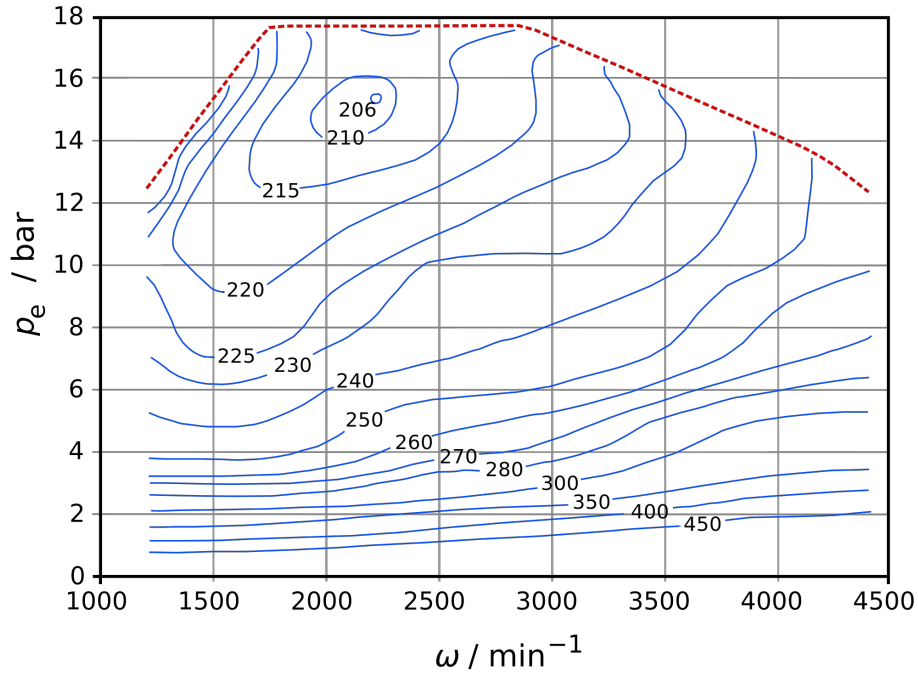


Figure 2.3: Engine efficiency (g/kW*h) [14]

2.3 Transmission

The transmission used in the tractor is a continuously variable transmission, CVT. This means that the transmission is a stepless gearbox and it can deliver gear ratios between the standard fixed gears. There are many different approaches to construct a CVT, in this gearbox this is done with a shifting drum containing the fixed gears and a hydrostatic unit that delivers the continuously variable part. This gearbox is a so called powersplit transmission that is a combination of a mechanical and a hydrostatic transmission. An overview of the CVT can be seen in Figure 2.5. The CVT also has a PTO, power take-off unit, which can be used to connect implements to the vehicle. This affects the output to the wheels since some power from the gearbox is diverted to the PTO instead. The torque flow of the gearbox is shown in Figure 2.4.

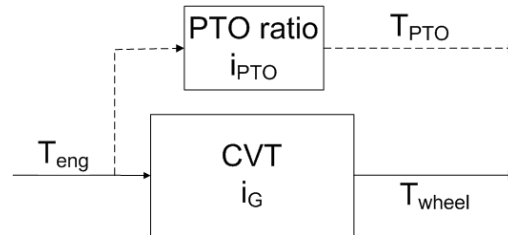


Figure 2.4: The torque flow of the CVT.

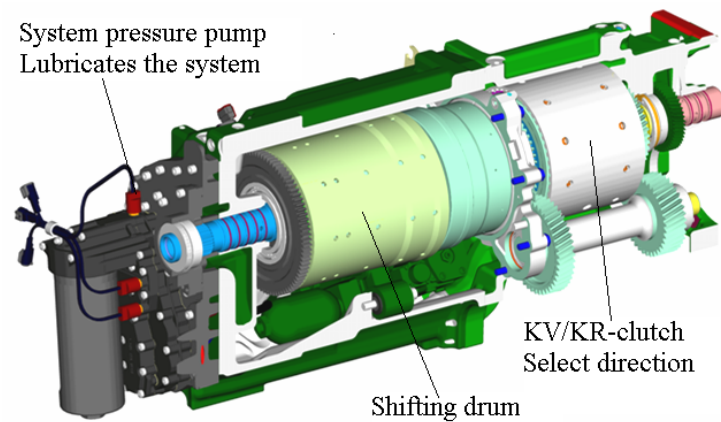


Figure 2.5: ECCOM interior view [1] - The hydrostatic unit is better shown in Figure 2.9

2.3.1 Shifting drum

The shifting drum contains four clutches and four planetary gear sets, as seen in Figure 2.6, where the clutches decide which parts of the planetary gear sets that should transmit power. The planetary gear sets consist of four parts, the sun gear, the planet gears, the ring gear and the planetary gear carrier. Figure 2.7 shows how these parts are connected.

The ring gear of the first planetary gear set is connected to the input shaft of the transmission and is thereby driven by the engine. The sun gear of the same planetary gear set is controlled by the output from the hydrostatic unit. The planetary gear carrier is used to transmit power from one planetary gear set to the ring gear of the following planetary gear set. The output from the fourth planetary gear set is connected to the KV/KR-clutch, as can be seen in Figure 2.5, which is used for forward or reverse drive. The KV/KR-clutches give the vehicle four gears when driving in both directions thus giving the vehicle full speed in the reversed direction as well. The output of the KV/KR-clutch is connected to the differential.

Clutches

The clutches in a ZF CVT make sure that there is no gap in the power transfer, unlike regular cars where no power is transferred during the gear switch. This type of gap free transmission is known as a powershift transmission. There is an overlap of the gear ranges so one range is always transferring the power from the engine. This is done by engaging and disengaging the clutches at the same time.

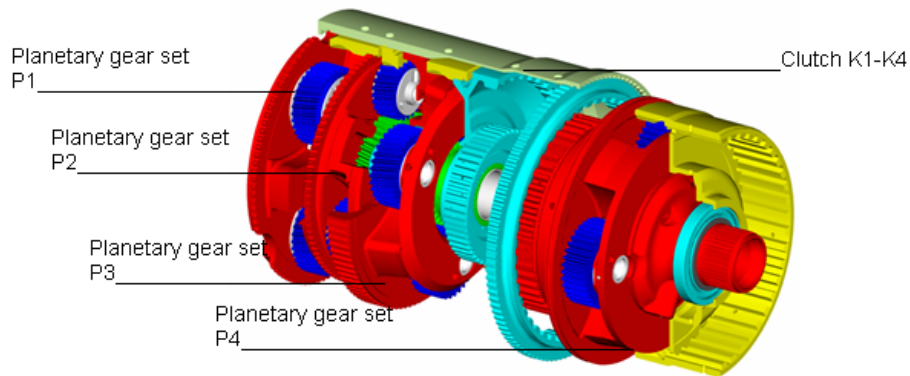


Figure 2.6: Shifting drum interior view [1]

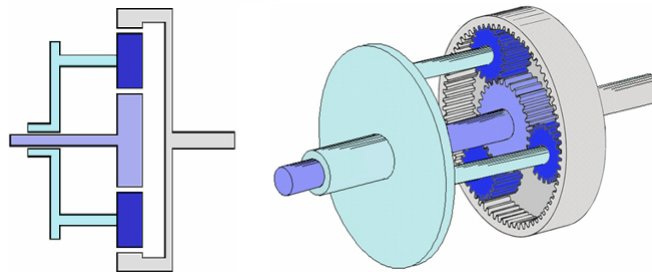


Figure 2.7: Planetary gear set, sun gear purple, planet gears blue, ring gear grey and planetary gear carrier cyan.

2.3.2 Hydrostatic unit

The hydrostatic unit allows for a continuously variable gear ratio for the vehicle. It consists of a fixed and a variable displacement pump which are connected to each other by a liquid flow in both directions. The variable displacement pump is driven by the engine and consists of a swash plate and pistons as shown in Figure 2.8. By changing the angle of the swash plate the output flow and direction of the pump can be altered, thus creating the continuously variable part of the transmission. The fixed displacement pump has the same design as the variable displacement pump except that the swash plate is in a fixed position and is connected to the shifting drum. It supplies the shifting drum with an additional rotational power that depends on the flow received from the variable displacement pump. How the hydrostatic unit is connected to the shifting drum can be seen in Figure 2.9.

2.4 Advantages of CVTs

In agriculture, heavy machinery and implements are being pulled by the tractor which therefore has a large need of torque. This makes the CVT a good choice

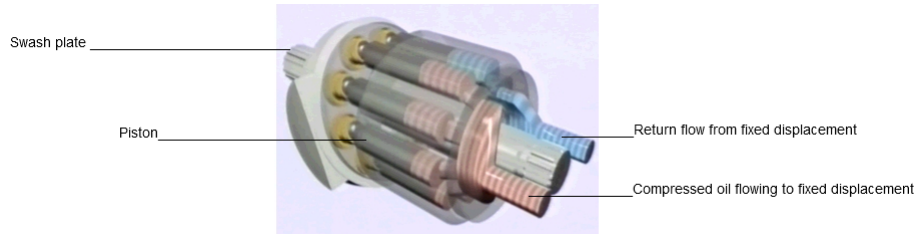


Figure 2.8: Hydrostatic unit

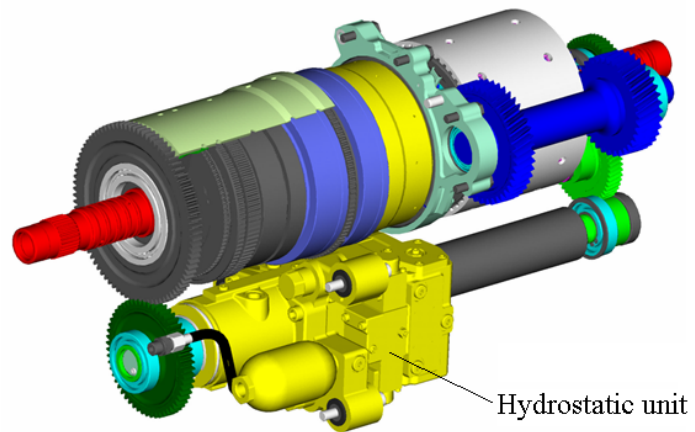


Figure 2.9: The hydrostatic unit connected to the shifting drum [1]

since it has a gear ratio beginning at zero. This means that the agriculture vehicle can perform heavy work at very low speeds. The CVT will, according to Equation 2.3, have "infinite"¹ torque when the gear ratio goes towards zero. The benefits have been listed in Table 2.1.

$$n_{eng} \cdot i_G = n_{out} \quad (2.2)$$

$$\frac{\tau_{in}}{i_G} = \tau_{out} \implies \lim_{i_G \rightarrow 0} \tau_{out} = \infty \quad (2.3)$$

where i_G is the transmission reciprocal ratio, TRR .

<i>Feature</i>	<i>Benefit</i>
Constant, stepless acceleration from a complete stop to cruising speed	Eliminates "shift shock" - smoother ride
Works to keep the vehicle in its optimum power range regardless of how fast the vehicle is traveling	Improved fuel efficiency
Responds better to changing conditions, such as changes in throttle and speed	Eliminates gear hunting as a vehicle decelerates, especially going up a hill
Better control of a gasoline engine's speed range	Better control over emissions
The ability to have a reciprocal ratio equal to zero	Better handling of lower speeds and the ability to stop in slopes without a hill holder system.

Table 2.1: Advantages of CVT [12].

2.5 Vehicle control units

In the vehicle there are several control units, which are explained below. These are used to control the different parts of the powertrain. A flowchart of how these control units interact with each other, the engine and the gearbox can be seen in Figure 2.10.

VDC The vehicle drivetrain control unit has access to both the CAN-buses and sends the reference signals to the ECU and TCU. This unit contains the driveline strategy which has the information on how the vehicle should behave in different situations. All the inputs from the driver goes via the VDC and all the actions performed is decided by the driveline strategy of the VDC. This means that the driver is not in direct control of the gear ratio nor the engine speed. Apart from the inputs of the driver the

¹Infinite in theory since in reality the tires will start slipping when the torque becomes too high.

surrounding inputs, such as various loads and environmental conditions, are processed by the driveline strategy.

ECU The engine control unit takes the *rpm* reference signal from the VDC and controls the engine so that the reference is followed when possible.

TCU The transmission control unit takes a gear ratio reference from the VDC and controls the gearbox so that the reference is followed. This is done by controlling the hydrostatic unit and shifting the clutches.

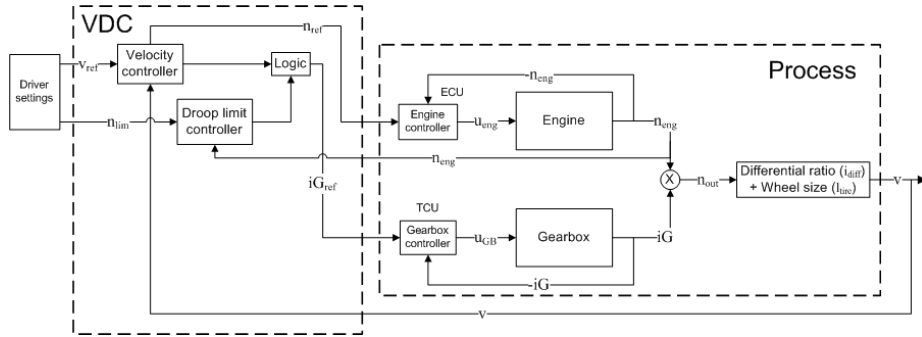


Figure 2.10: Overview of the controlled process where the box named logic represent different approaches to solve the gear alternation.

2.6 Connection overview

In the vehicle there are two CAN buses; CAN vehicle and CAN local, which are used for communication between the different control units. To implement the control strategies of this thesis a MAB was connected to the CAN local bus. In Figure 2.11 the connections between the different units can be seen.

2.7 Droop limit

The droop limit is a setting that is chosen by the driver and is the only known mode when gear alternation occurs. It is a limit that the engine speed will not drop below. If heavy load is applied on the tractor the *rpm* of the engine will start to drop. When the *rpm* reaches the droop limit the gearbox will start gearing down. This action will give more torque to the vehicle, thus allowing the vehicle to handle the large load. Preventions against further drop of the *rpm* is then acquired. The droop limit is defined as a percentage level of the maximum *rpm*. It can be used to prevent the engine to drop below the torque peak, the power peak or whichever limit favorable by the driver. Figure 2.12

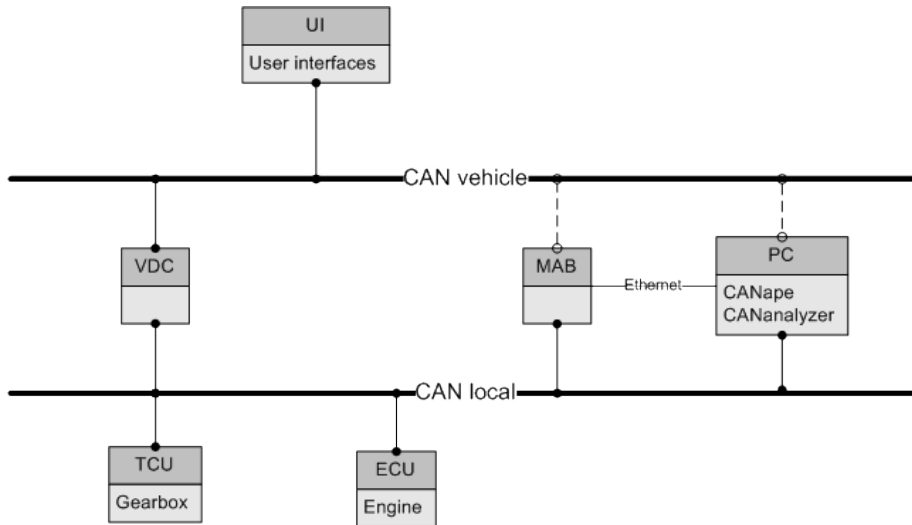


Figure 2.11: The CAN bus connections between the control units and the MAB in the tractor. Solid lines show connection used, dashed lines show possible connections.

describes how the droop limit influences the rpm and gear ratio during load. It can be seen that without any load the rpm of the engine is quite low which is done to save fuel. When the tractor lowers a tool into the ground the load increases whereupon the engine rpm is pushed down towards the droop limit. As the droop limit is reached the gearbox starts lowering the gear ratio. This action allows the vehicle to handle the larger load while preventing the engine from dropping further.

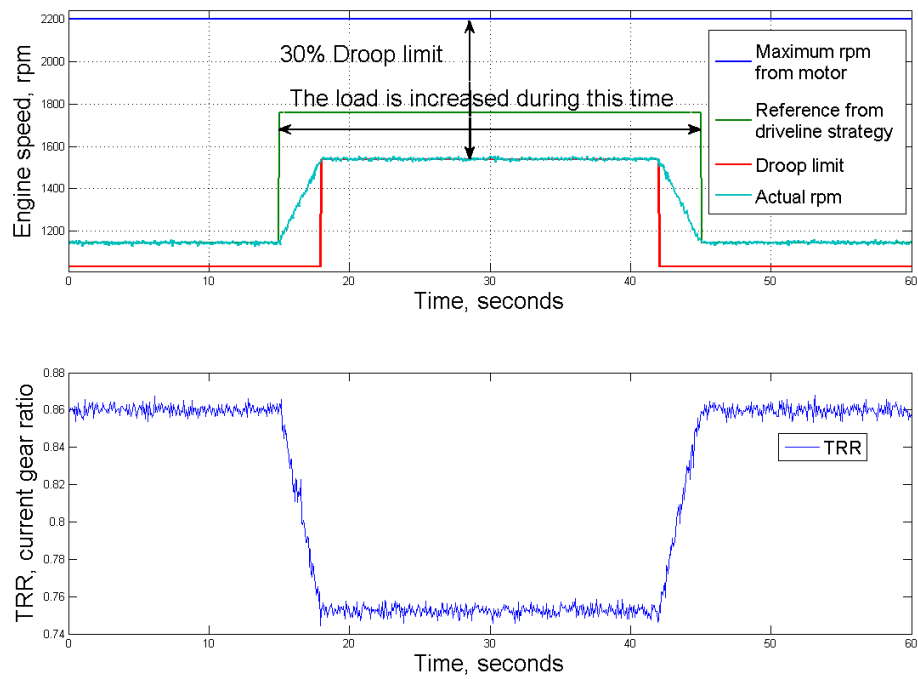


Figure 2.12: The droop limit effect on the engine *rpm* and the gear ratio. An enlarged version of the picture can be seen in Appendix B.

Chapter 3

Analysis

3.1 Gear alternation

The gear alternation occurs when the droop limit and the vehicle load are poorly combined. This is since the current driveline strategy always tries to push the gear ratio as high as possible. When the vehicle is under load it will get pushed down towards the droop limit. If the highest possible gear ratio that the vehicle can obtain with that load happens to be at a gear shifting point the gear alternation may start. The conclusion that the problem has two different approaches was made. Since the load can not be modified the approaches to adjust the droop limit and limit the gear ratio were investigated. The methods investigated to obtain this are described in Section 4. To see if there was any advantage of the higher or lower gear an efficiency analysis was performed on the Simulink model of the gearbox. The steps to obtain this data can be studied in Section 3.2. If the gear alternation would occur due to load variations a solution would be hard to find. Most of those alternations are probably needed for the tractor to handle the alternating load. The background information provided by ZF states that the gear alternation occurs with a frequency of approximately 1 Hz. It is unlikely that the load would alternate with the same frequency if the gear alternation is not only caused by the alternating load. The load of the vehicle will not be constant when driving on the field due to variations in the soil and terrain. This may be the cause of some of the alternations and those alternations may be hard to suppress. The gear alternation on a tractor driving in field can be seen in Figure 3.1. The following signals are shown:

- The speed reference to the engine, *RSSL*. (Red)
- The engine speed also know as the transmission input shaft speed, *TISS*. (Green)
- The state of the gearbox (shifting or no shifting), *TRS*. (Yellow)
- The gear ratio of the gearbox, *TRR*. The gear shifting point is slightly different on this gearbox and it occurs at 0.45. (Purple)



Figure 3.1: Gear alternation during field drive.

- The engine load, *PLACS*. (Orange)
- The current gear. (Cyan)

3.2 Gearbox efficiency

To make a more accurate decision regarding the choice of gear an efficiency table for the gearbox may be used. From this better choices can be made regarding staying in one gear or changing to the next. In the gearbox efficiency chart, which can be seen in Figure 3.2, the efficiency of the four gear ranges with the influence of the hydrostatic unit is shown. The efficiency of the gearbox is calculated from Equation 3.5. The deriving of that equation can be followed in Equations 3.1 to 3.5.

$$\eta = \frac{P_{out}}{P_{in}} \quad (3.1)$$

where

$$P_{out} = \tau_{out} \cdot n_{out} \quad (3.2)$$

$$P_{in} = \tau_{eng} \cdot n_{eng} \quad (3.3)$$

If Equations 3.3 and 3.2 are used in Equation 3.1 the following equation is obtained:

$$\eta = \frac{\tau_{out} \cdot n_{out}}{\tau_{eng} \cdot n_{eng}} \quad (3.4)$$

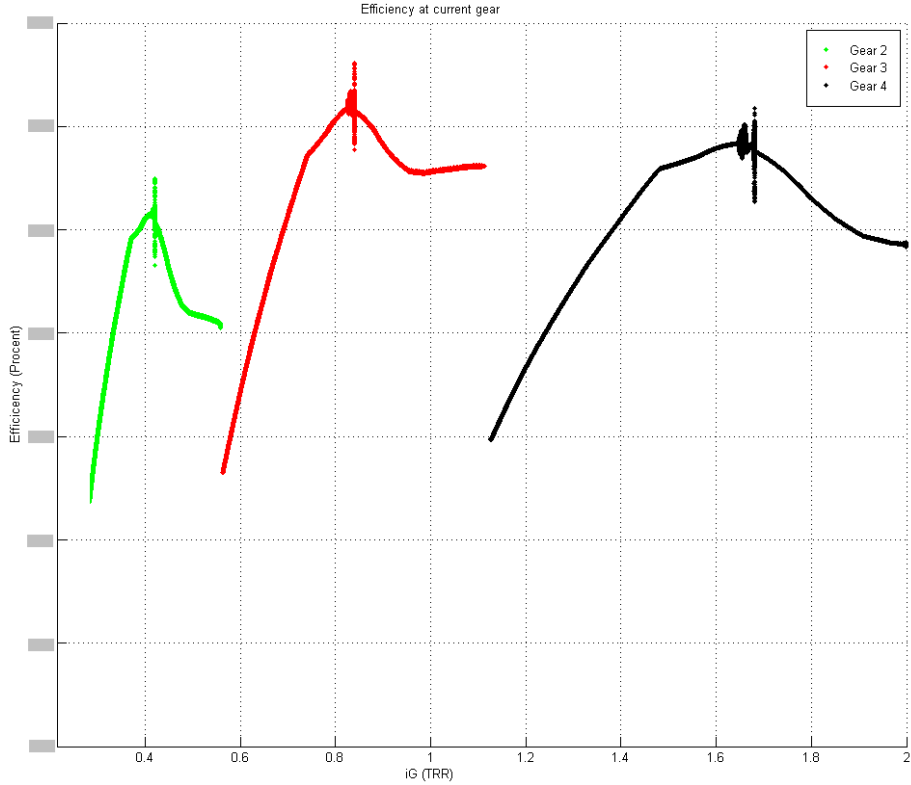


Figure 3.2: Efficiency chart of the ECCOM 1.8

i_G is defined as the ratio between n_{out} and n_{eng} ($\frac{n_{out}}{n_{eng}}$). If this is used in Equation 3.4 the following equation is obtained:

$$\eta = \frac{\tau_{out} \cdot i_G}{\tau_{eng}} \quad (3.5)$$

To obtain the efficiency chart a special load controller was developed. This controller increases or decreases the load of the vehicle depending on *PLACS*, the current engine load percentage. Since the gearbox can handle a very large span of loads on the vehicle a ordinary controller could not be found. The controller tries to keep the *PLACS* between 99.5 – 99.7%. If the *PLACS* goes below this limit the vehicle load is increased and if the *PLACS* goes above the vehicle load is decreased. The Simulink model for the controller can be seen in Figure 3.3 and the control actions taken in different regions can be seen in Table 3.1.

The data for Figure 3.2 was obtained by keeping the *rpm* fixed, which can be seen in Figure 3.4. This was done while slowly decreasing the reference to the gearbox, *CTRR*. The *CTRR*, *TRR* and *ITRR* can be seen in Figure 3.5.

PLACS value	Load increase / decrease
< 99%	+0.05%
< 99.2%	+0.03%
< 99.3%	+0.01%
> 99.5 & < 99.7%	No action preformed
> 99.7%	-0.01%
> 99.8%	-0.03%
> 99.9%	-0.05%

Table 3.1: Load control action table, depending on the deviation from the desired *PLACS* different actions are performed.

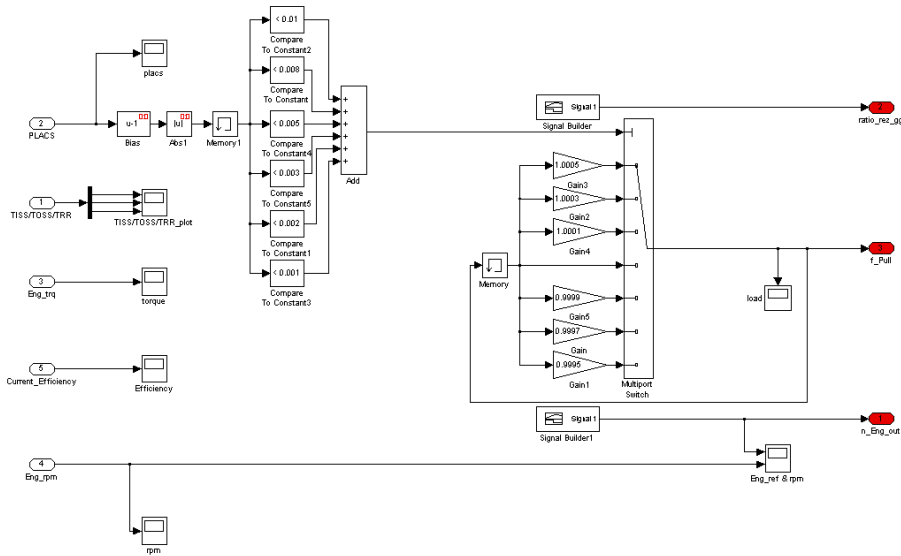
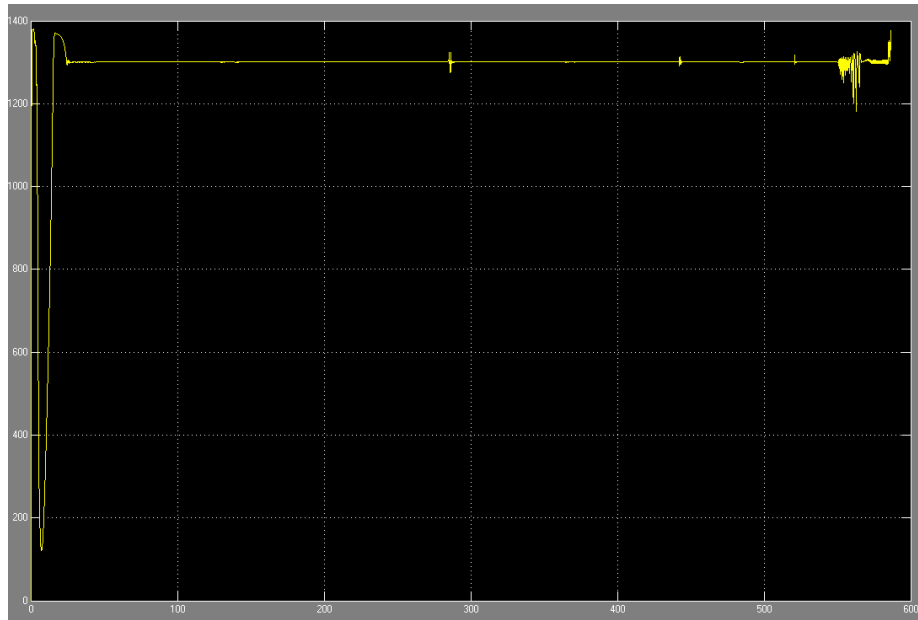
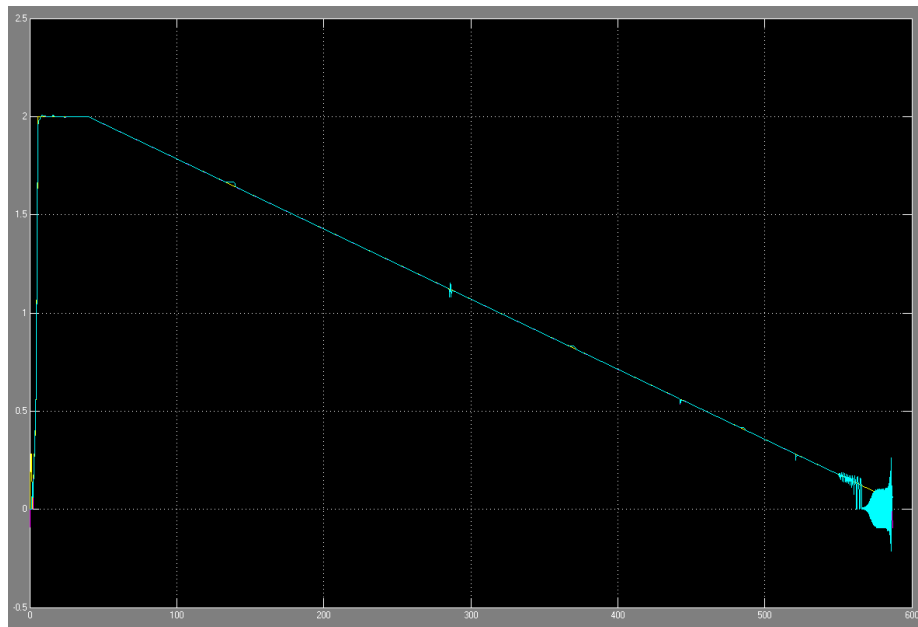


Figure 3.3: Simulink model of the load controller

In this figure the switching points between the gears and the change of the direction of the hydrostatic unit can be seen. In the high region of a fixed gear range the hydrostatic unit "pushes" to acquire a higher *TRR* and in the lower half of the gear range the hydrostatic unit "breaks" to gain a lower *TRR*.

The small disturbances that can be seen in Figure 3.5 correspond to changes in the direction of the hydrostatic unit and changes between the fixed gears. These disturbances have been marked in Figure 3.6.

The reason why it is not possible to get a good read of the efficiency at the end of the run is because the vehicle load capacity increases exponentially. The load controller can not handle this to adjust the load in a proper way. In figure 3.7 the load during the run can be seen. As can be seen the load increases inversely proportional to *TRR*, which means that theoretically the tractor can

Figure 3.4: *Rpm* during efficiency runFigure 3.5: *CTTR/TRR/ITRR* during efficiency run

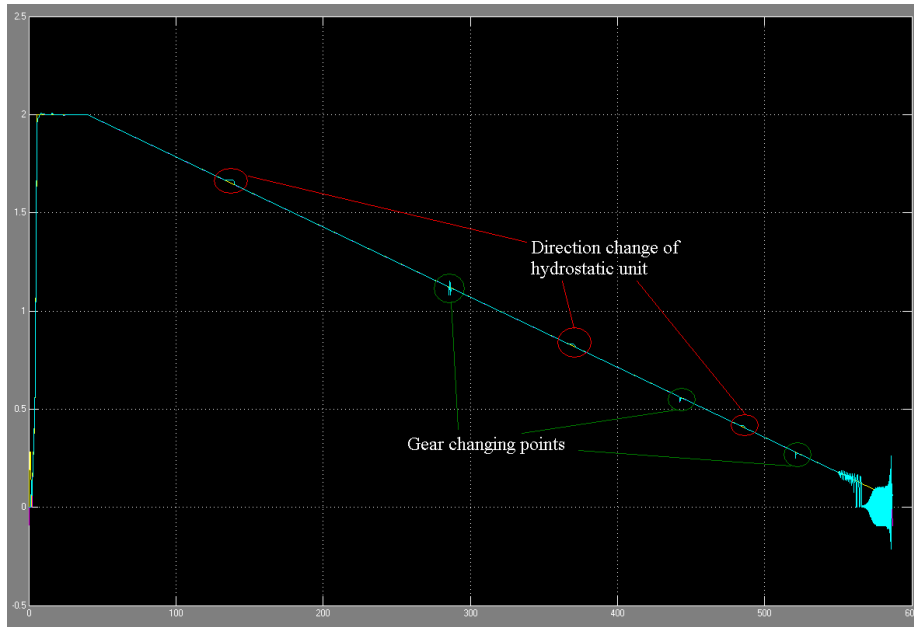


Figure 3.6: $CTTR/TRR/ITRR$ during efficiency run showing when the direction of the hydrostatic unit changes and the gear changes

handle infinite load at $TRR = 0$. In Figure 3.8 a zoom of the load in the area where the efficiency actually was plotted is shown.

As can be seen in Figure 3.2 the load controller starts getting problems when TRR is getting small. This is the reason why Figure 3.2 starts at 0.18 instead of 0. The reader should notice that Figure 3.2 goes from gear ratio 0 to 2, while the other figures go from 2 to 0.

3.2.1 Gear efficiency effect - needed rpm

Since different gear ranges have different efficiency a higher engine torque might be needed to compensate for the torque lost in the gearbox. Example 1 illustrates this phenomenon with data from the Xerion 5000 [13] and with a gearbox that has an efficiency jump of 2% for example.

In the gear range shift between the second and third gear the efficiency difference is around 2% (at 1500 *rpm*). If the driver, for example, has set the droop limit to 1600 *rpm* the engine gives a torque of 2248 Nm. The loss of 2% is equivalent to a loss of 46.08 Nm at this droop limit. This denotes that if the less efficient gear is chosen the *rpm* of the engine needs to be altered so that the torque output is 2294.1 Nm instead. To acquire 2294.1 Nm a *rpm* of 1531 is needed i.e. a 69 *rpm* lower value than the original 1600 *rpm*.

Example 1: An example of the effects of the efficiency differences between two gears. This example was calculated according to list 1.

The efficiency loss between the gears is calculated with Equation 3.6.

$$\eta_{loss} = \frac{E(i_H) - E(i_L)}{E(i_G)} \quad (3.6)$$

$E(i_G)$ gives the efficiency at i_G

The needed torque due to the less efficient gear is calculated with Equation 3.7.

$$\tau_{need} = \underbrace{T(n_{dim})}_{\text{Original torque}} + \underbrace{T(n_{dim}) \cdot \eta_{loss}}_{\text{Extra torque}} \quad (3.7)$$

$T(rpm)$ gives the torque at rpm

The *rpm* needed to acquire the higher torque is calculated from Equation 3.8.

$$n_{need} = \underbrace{R(\tau_{need})}_{\text{R(torque) equals the rpm needed to acquire torque}} \quad (3.8)$$

The size of the needed *rpm* change is calculated with Equation 3.9.

$$n_{change} = abs(n_{dim} - n_{need}) \quad (3.9)$$

Calculation 1: The list describes the step for how to calculate the size of the *rpm* change needed to handle the efficiency loss in a gear change. This example could also be used to calculate the size of the limits that are used in Criteria 1 and 3 described in Section 4.3. The size of the droop limit adjustment could also be estimated from this equation. For further description regarding functions and variables used see Page ix.

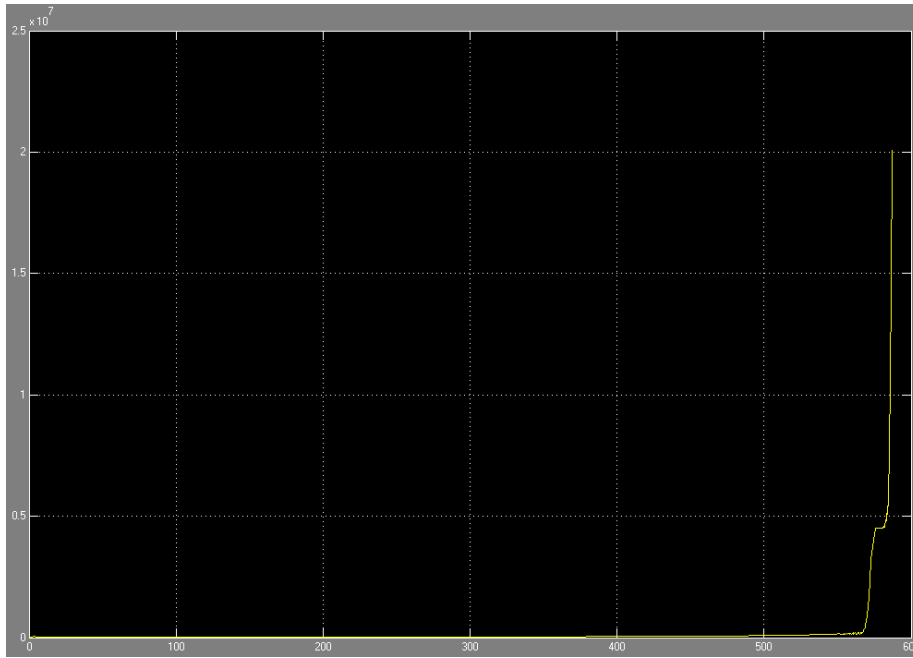


Figure 3.7: The load during the run

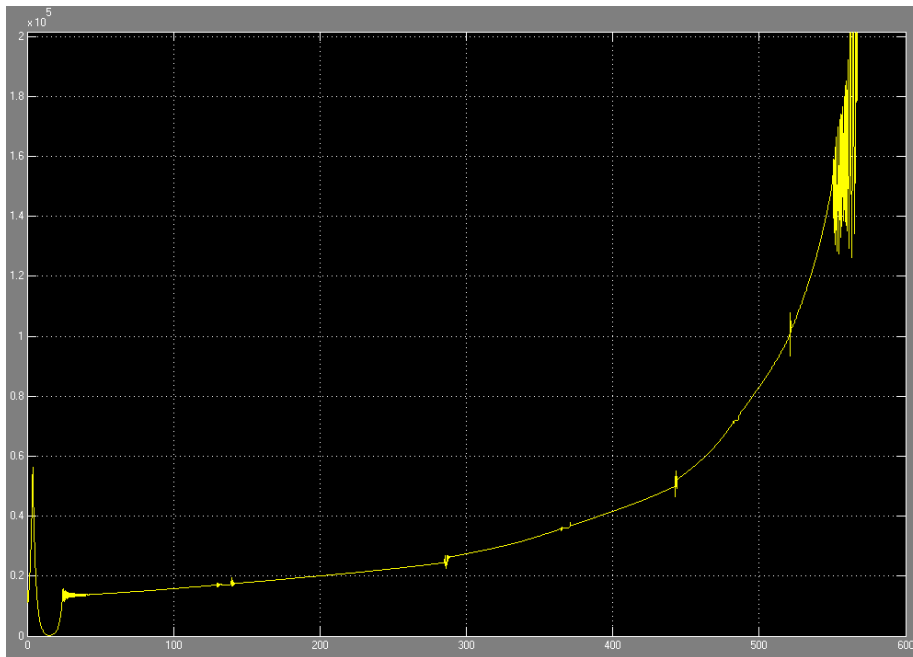


Figure 3.8: The load during the run

Chapter 4

Method description

4.1 Hardware and software description

4.1.1 Test environments

As previously mentioned the algorithm development consists of three steps which are further explained below.

Simulink model

A model of the engine with the including gearbox was supplied by ZF. To this model a simplified version of the VDC as well as the problem scenario were developed by the authors of this report. This Simulink model was used to construct and to perform the first test of the possible solutions. The MAB was not used in this step. The shifting point between the second and third gear occurs at 0.56 *TRR* at the gearbox implemented in this model.

Tractor simulator

The tractor simulator consisted of a computer that simulated the vehicle output, but to this simulator hardware such as the VDC was connected as well. This was used to check the software before testing on the real tractor. This system is a so called hardware in the loop simulator. The shifting point between the second and third gear occurs at 0.56 *TRR* at the gearbox implemented in this model.

Claas Xerion 5000

As the final step of validation the software was tested on the real tractor on a test track. To obtain the problem with gear alternation on the test track a braking wagon was connected to the tractor to simulate the load. The shifting point between the second and third gear occurs at 0.37 *TRR* at the gearbox installed in this tractor.

4.1.2 MicroAutoBox II

MicroAutoBox II, see Figure 4.1, is a real-time system which is used for controlling Rapid Control Prototyping¹ applications, e.g. electric drive control, powertrain and aerospace applications. In our case, the MAB is connected to the VDC, the ECU and the TCU via a CAN-bus and is used to implement our supplemental control algorithm on the real tractor. The box is programmed by building a model in Simulink. The model is then translated to C-code and downloaded to the box with the help of the MathWorks Real-Time Workshop [4] (also known as Simulink Coder). From there the model can operate automatically, without any human input. At the same time, the signals and parameters in the MAB can be accessed in real-time by the user through a CAN or Ethernet connection.



Figure 4.1: MicroAutoBox II [2]

4.1.3 Data collection

To monitor and debug the program running on the MAB and the signals on the CAN a CANcaseXL log, see Figure 4.2, is connected to the CAN. The CANcaseXL log is also connected to a PC via USB. Thereby it is possible to change parameters and view signals in the program running on the MAB as well as view and create signals on the CAN, all in real-time. This monitoring is done with two programs, CANalyzer and CANape, where CANalyzer grants the ability to work with the CAN and CANape the ability to work with the program running on the MAB. It is also possible to use an Ethernet connection between the PC and the MAB to access the parameters and signals on the box. This option is advantageous since more data may be collected since the Ethernet has a larger capacity. This was also confirmed by empirical experiments.



Figure 4.2: CANcaseXL [5]

¹"Rapid Control Prototyping or RCP is a process which lets the engineer quickly test and iterate their control strategies on a real-time computer with real input/output devices." [3]

4.1.4 CANalyzer

With CANalyzer, see Figure 4.3, it is possible to read messages that are sent on the CAN as well as create new messages to send on the CAN. The blue squares in the main window can be used to alter existing messages or create new ones. In this case, the IG-box² has been created to send a message to the CAN, see Figure 4.4. The message has been given a unique identifier and a signal has been added to the first byte of the message. In the Trace-window, see Figure 4.5, all the signals on the CAN are displayed in a time-based list. In this list a message with identifier 64 is received by CANalyzer at regular intervals and the message from Figure 4.4 is sent once. Signals can also be read from a file with stored data from a real application.

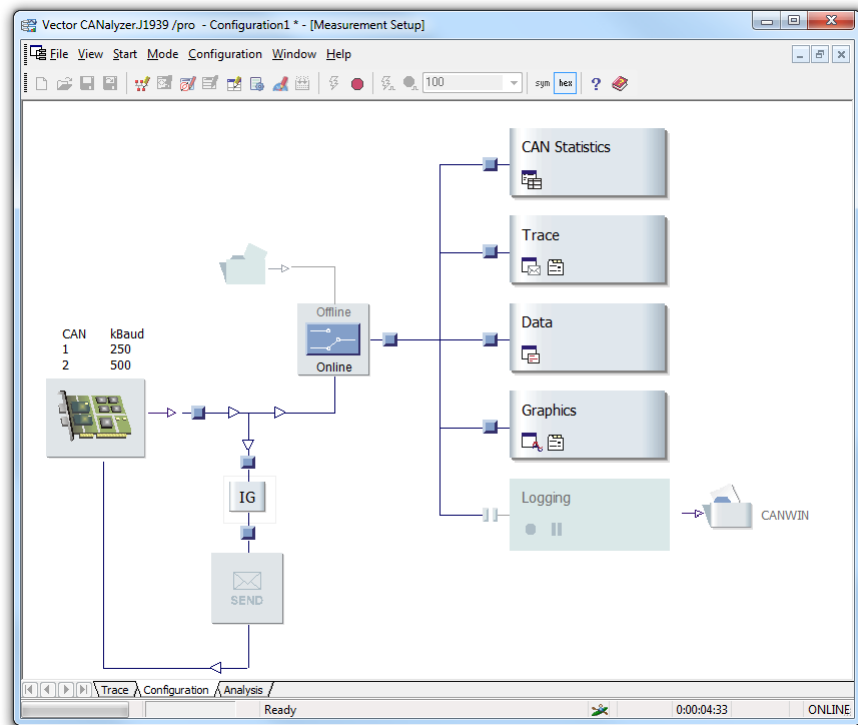


Figure 4.3: CANalyzer

4.1.5 CANape

With CANape, see Figure 4.6, it is possible to view signals and change parameters in the program running on the MAB. This is done by creating devices from

²This has no connection to the transmission ratio, i_G

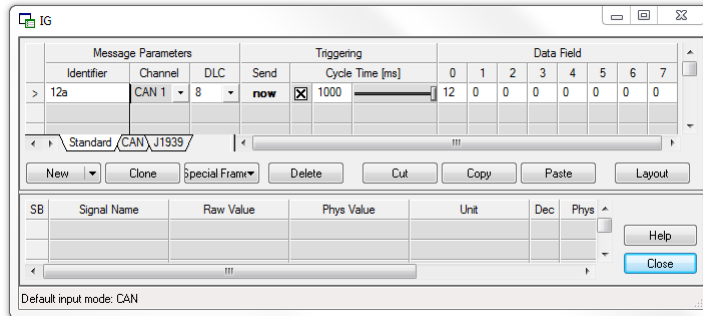


Figure 4.4: CANalyzer IG

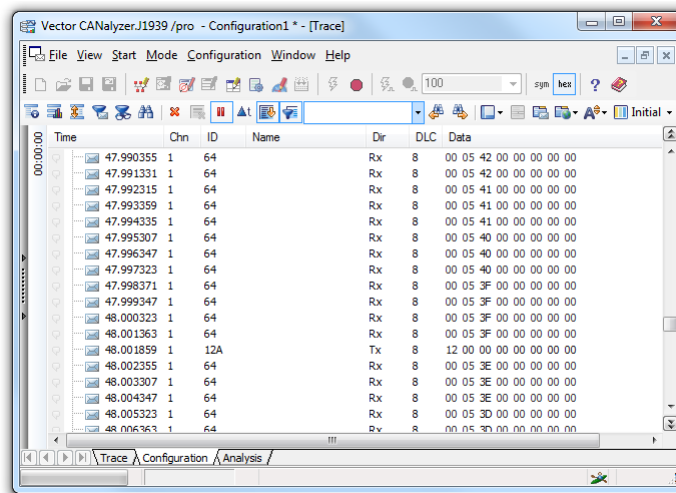


Figure 4.5: CANalyzer Trace

different databases. This can for example be a database of all the messages sent on a CAN or all signals and parameters in an application like the MAB. These devices can then be used to add individual signals and parameters to the display and calibration windows. In the display windows the value of signals and parameters can be displayed in various ways, for example graphically, digitally or numerically. In calibration windows parameters can be changed by simply entering a new value in the corresponding field. Each signal and parameter can also be recorded so that the measurements are available after the measurement has ended.

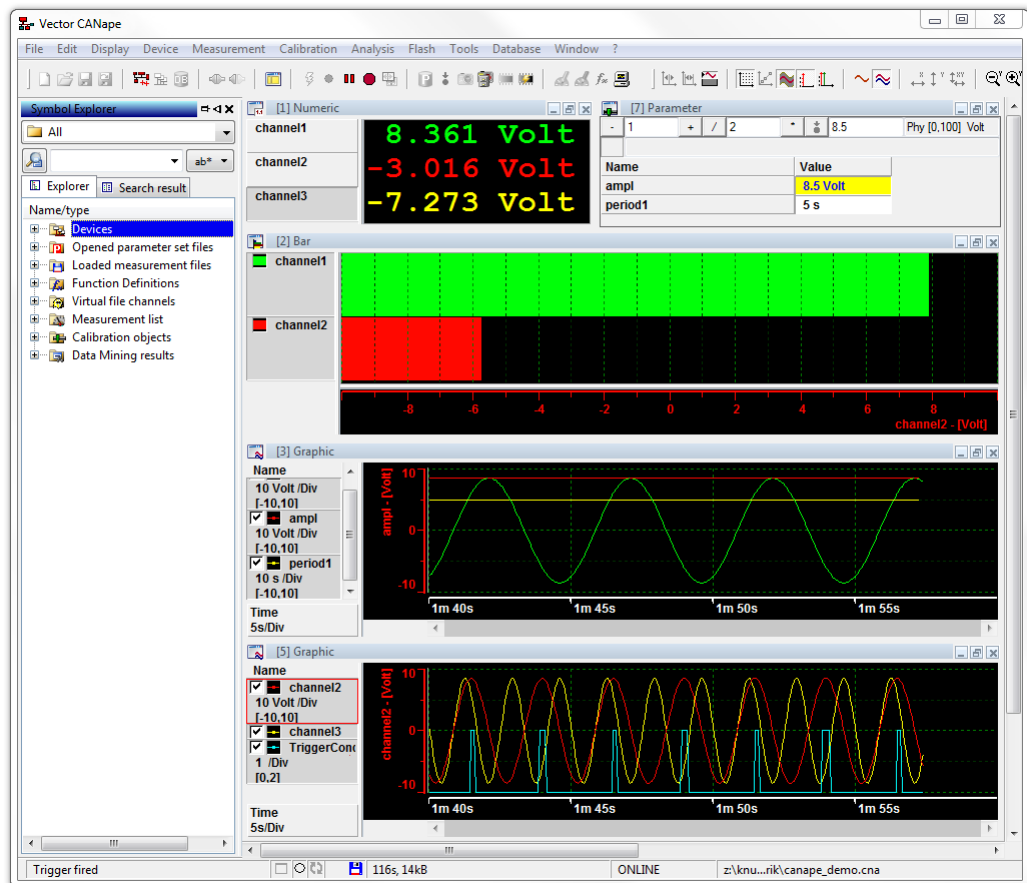


Figure 4.6: CANape

4.2 Setup

Two computers were used during the thesis. One of them was used to conduct the simulations of the gearbox and the engine in Simulink. To achieve this a model with the for us important functions of the VDC were created. Then the settings to trigger the gear alternation was empirically found. Once the gear alternation problem was found different solutions to fix it were attempted. If a solution proved to be functional it was extracted from the file and further processed on the other computer. This computer was mainly used to connect to and transfer the program to the MAB. In the beginning a lot of work was put into installing and learning the required software as well as getting the communication working between the computer, the CAN-bus and the MAB. When communication had been properly configured the solutions were programmed to the MAB. After this step was completed the MAB was connected to a tractor simulator. With the computer still connected to the MAB the solutions were further tested and evaluated. When a satisfying result was achieved the software was further tested on the real tractor. The first tests were conducted with a brake trailer connected to the tractor. A brake trailer is a trailer with a controllable retarder that brakes the wheels of the trailer.

4.3 Possible approaches

Since a solution that interfered as little as possible with the current strategy was preferred no large controllers for the entire VDC were developed. Instead small alterations to the existing strategy were implemented and tested. As mentioned in Section 3.1 the problem with gear alternation occurs when the engine is under heavy load and is pushed to the droop limit. This problem only occurs if the load is of the size so that the gear ratio is pushed down to the switching point between the second and third gear. Since there are no implements forcing the tractor to run at the first and third gear shifting point the problem does not occur at these points.

The existing strategy tries to push the gear ratio as high as possible. At the same time the engine *rpm* is kept at the droop limit. Therefore alterations of the reference signals were attempted. No attempts were made to change the *rpm* reference to the ECU since it was controlled indirectly by the droop limit. Instead the approach of changing the droop limit was investigated. Different criteria were identified to trigger the various solutions so that they will not be active when gear alternation are not possible. Each solution uses one or more of the following criteria:

1. A region that the *TRR* should be within, i.e. a hysteresis from the switching point where *TRR* equals 0.56. This makes sure the gear ratio is within the limits of gear alternation.
2. A limit that the engine load percentage, *PLACS*, should be above, in our case 98%. This was chosen since gear alternation is only known to occur

during full engine load.

3. The rpm should be within 10% of the droop limit. This criterion is used to detect major load changes.
4. Detection of acceleration/retardation so that no alteration should be made when passing through the gear shifting point. This criterion was only used in the Simulink model due to difficulties when implementing it on the real process.
5. The derivative of the velocity error³. If the error increases or decreases rapidly no precaution should be taken.
6. The velocity error should be positive if a precaution should be active. In the case that the reference is changed by the driver no approach should be active.

4.3.1 Droop limit adjustments

Different approaches to adjust the droop limit were developed. By adjusting the droop limit the engine gets less or more power which will result in a lower or higher gear. This action will alter TRR so that it is not at the shifting point. These approaches are described below and the difference between them can be seen in Figure 4.7. The size of the droop limit adjustment can be calculated with the equations in Calculation 1 in Section 3.2.

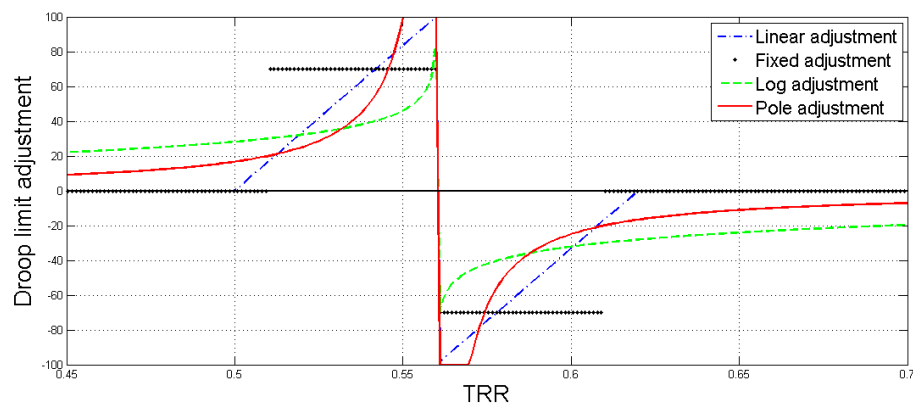


Figure 4.7: The different adjustments made to the droop limit by the different approaches.

³The velocity error is the difference between the velocity reference and the actual velocity.

Fixed adjustment

When Criteria 1 and 2 are active the droop limit is increased or decreased by $X\%$ ⁴. The effect is that the TRR can be placed slightly higher or lower than the gear shifting point. Since the fixed adjustment will alternate between being activated and deactivated a PWM, puls width modulation, will occur so the droop limit will in fact be pushed less than $\pm X\%$.

Pole adjustment

Version 1

When Criterion 4 is not active the droop limit is adjusted with the following function; $adjustment = \frac{K}{abs(TRR-0.56)}$. The size of the factor K decides how strong the adjustment will be and the sign of the factor influences if the adjustment should be positive or negative.

Version 2

During the project the conclusion that an active choice has to be made depending on if the droop limit should be increased or decreased. This conclusion led to that the absolute function was removed which means that the adjustment is either negative or positive depending on if TRR approaches the shifting point from above or below. Therefore, the adjustment used was $adjustment = \frac{K}{TRR-0.56}$. The impact this adjustment has on the droop limit can be seen in Figure 4.8. The effects that the pole adjustment has got on the rpm, the droop limit and the TRR can be seen in Figure 4.9.

Integration adjustment

When Criteria 1 and 2 are active an integration of a constant begins. Depending on the sign of the derivative of TRR the integral value is increasing or decreasing. The droop limit is then adjusted with this value. This value will converge towards the necessary offset to avoid alternation between gears.

Linear adjustment

When Criteria 2 and 4 are active a linear adjustment is applied. This is done when i_G is between 0.56 ± 0.04 , with the largest adjustment at 0.56 and no adjustment at the end points.

Logarithmic adjustment

The logarithmic adjustment works similar to the second version of the pole adjustment. The difference is that instead of adjusting the droop limit by a pole in the gear switching point the droop limit is adjusted through the equation $sign(TRR - 0.56) * \log(abs(0.56 - TRR))$. Unlike the pole adjustment the log adjustment starts to adjust the droop limit earlier and it is not quite as

⁴The X could be derived from Calculation 1.

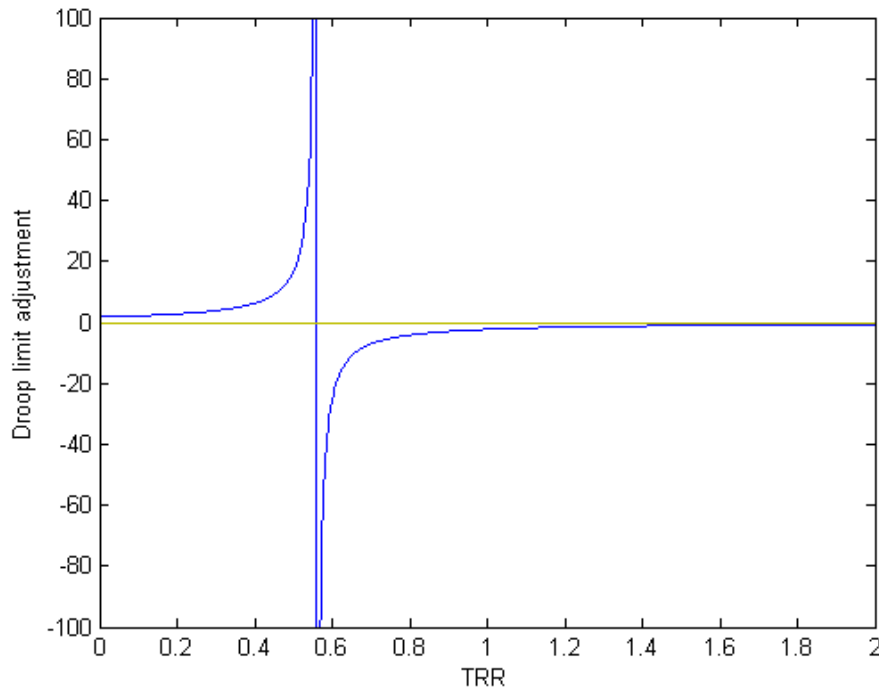


Figure 4.8: The adjustment made to the droop limit depending on the current TRR by the pole method.

aggressive close to the switching point. In Figure 4.10 the impact of the log adjustment can be seen.

4.3.2 Range shift limitation

The *RSL* approach prevents gear alternation by a lock-down of the gearbox. This means that gearing is only allowed in one direction, either up or down. By triggering on all the criteria the *RSL* is activated and thereby locking the gearbox. The criterion number 3 is needed in the case that the load increases during a lock of the gearbox in the third gear. This is done to prevent engine failure. In Figure 4.11 the effect that *RSL* has on TRR can be seen. The effects that the *RSL* approach has on the rpm and the TRR can be seen in Figure 4.12.

4.3.3 Torque limitation

The torque limitation approach lowers the maximum torque of the engine when within the critical region⁵. This forces the gearbox to lower the gear ratio so

⁵Critical region has the value 1 (true) if gear alternation is possible and 0 (false) otherwise.

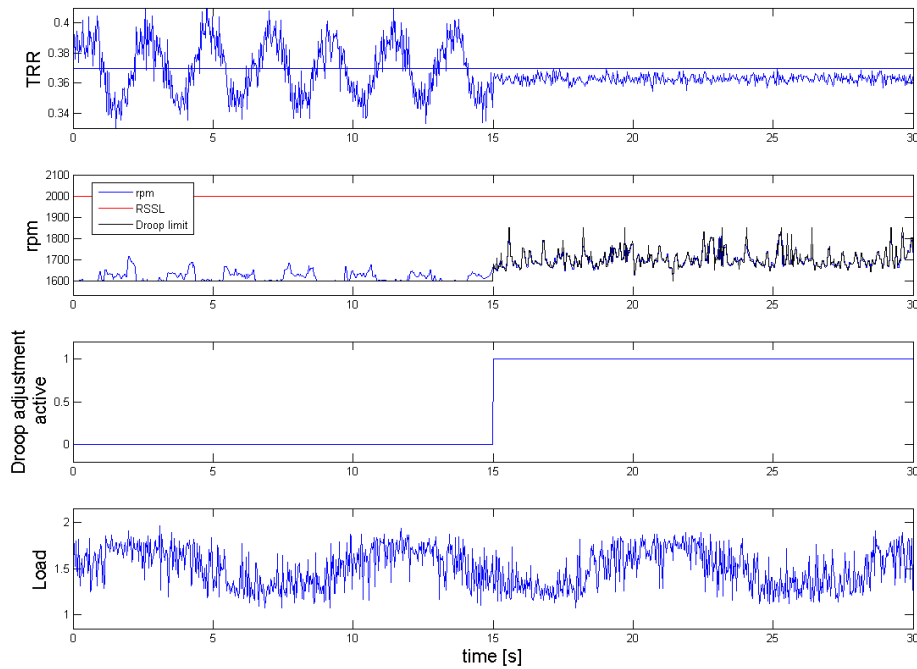


Figure 4.9: The pole adjustment effect on the whole system.

that the vehicle may handle the load when the engine has lowered torque. By this action the gear ratio will be pushed below the gear shifting point. This approach is limited to choose the lower gear of the gear switching point since only lowering of the torque is possible. The effect of the torque limitation can be seen in Figure 4.13.

4.3.4 Load dependent solutions

If a good estimation of the current load of the vehicle is available a controller that makes an active choice between the high respectively the low gear could have been used. Since load estimation currently is unavailable no more work has been put to this area but in further work these type of load depending solutions should be taken into consideration.

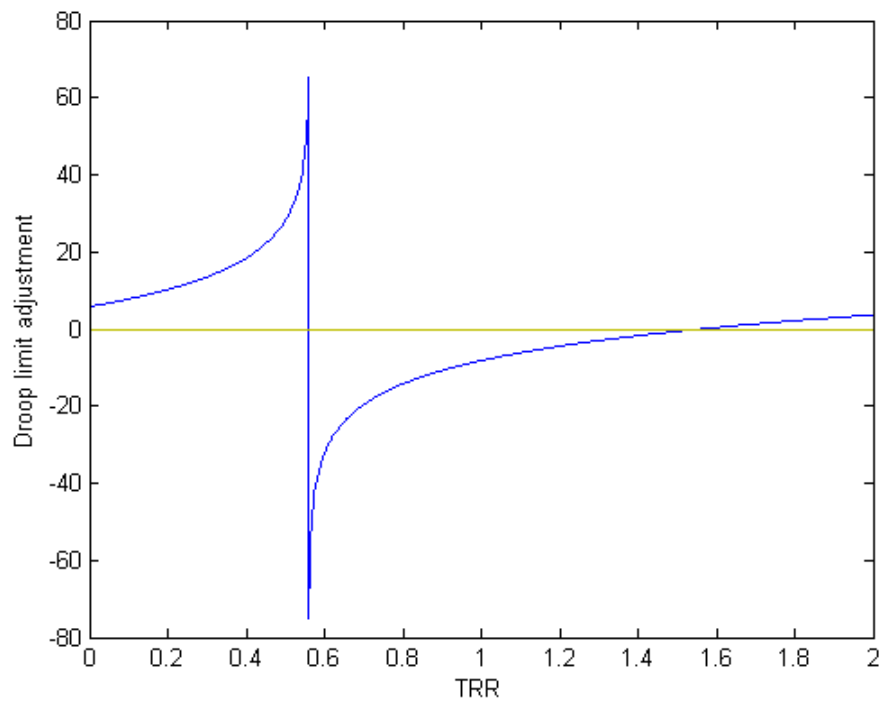


Figure 4.10: The adjustment made to the droop limit depending on the current TRR by the log method.

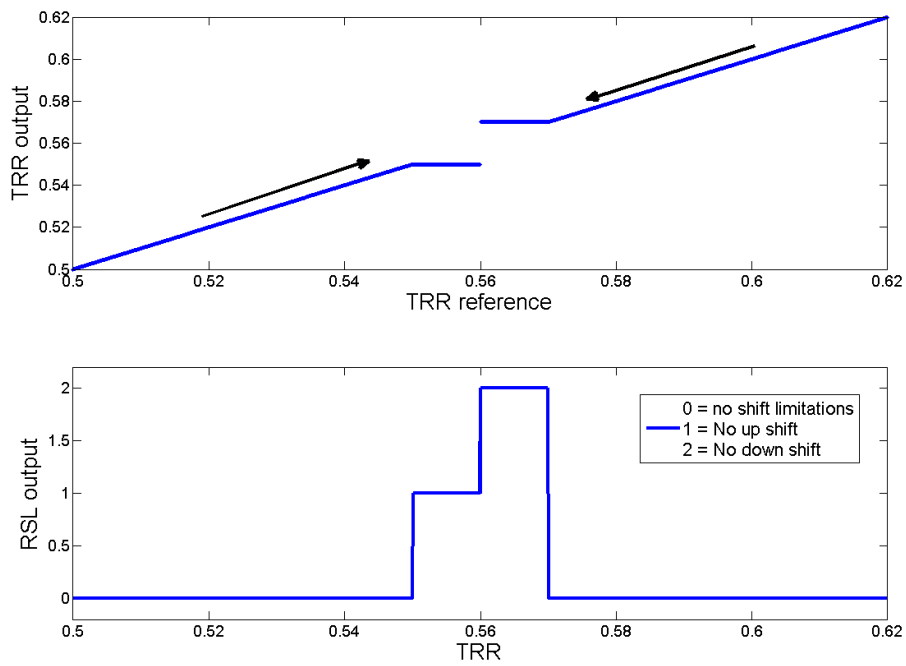


Figure 4.11: The effect on TRR for different values of the RSL .

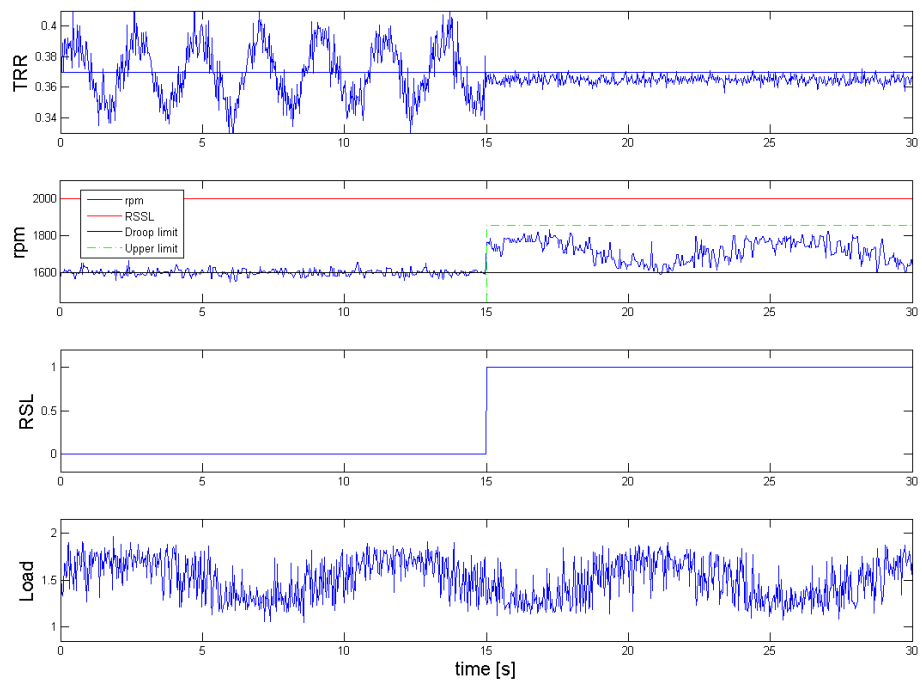


Figure 4.12: The effect on the system when RSL is set to prevent up shift.

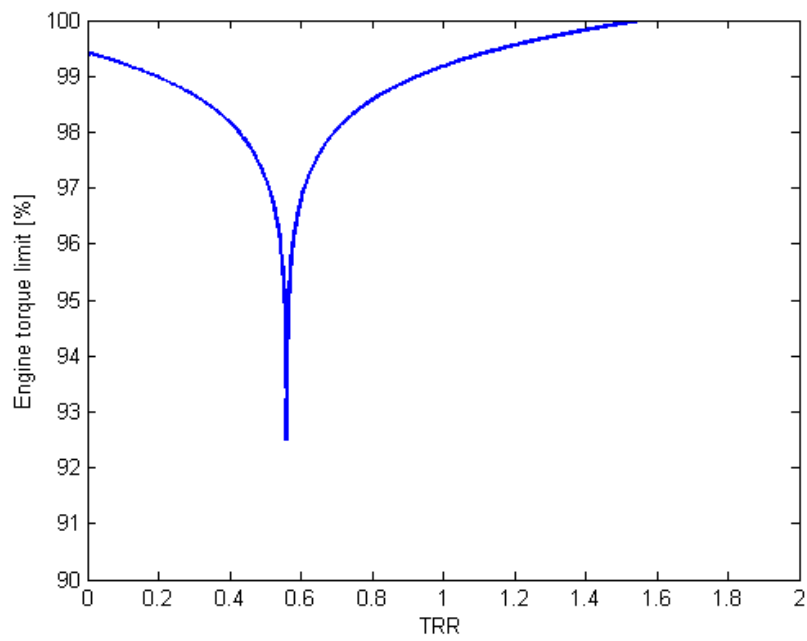


Figure 4.13: How the torque output of the engine is lowered within the critical region.

Chapter 5

Implementation

5.1 Simulink model of the VDC

A simplified version of the VDC was created in Simulink. This simplification could be done since not all of the functions implemented on the VDC were of interest for this thesis. The main parts created in the VDC were the velocity controller and the droop limit controller. Besides these regular functions of the VDC different solutions to solve the gear alternation problem were implemented. The engine reference controller was only simulated with a constant engine speed reference. An overview of how the different implemented blocks were connected can be seen in Figure 2.10.

5.1.1 Simulink block descriptions

Adaptive tuning of the velocity controllers I-part

By looking at the relative error between the velocity reference and the velocity error a factor is obtained which may be used to continuously change the influence of the I-part on the controller. By applying this modification a controller with a fast step response and a smooth control close to the reference value is obtained. To avoid aggressive control at the gear shifting point a secondary adaptation scheme depending on the signal critical region is also implemented. The second adaptation cuts 96-98% of the control signal if the risk for gear alternation is possible. See Figure 5.1 for an overview of the I-adaption block.

There are two controllers affecting the reference signal to the gearbox. The first is the main controller which makes sure that the desired speed is acquired, see Figure 5.2. The second is the droop limit controller that makes sure that the motor does not drop below a preset *rpm*, see Figure 5.3. The second controller makes sure that the gearbox and motor succeed with handling the current load of the vehicle even though that will result in an error in the desired velocity. The velocity controller consist of only an I-part in our model. This is implemented to retrieve a controller that follows well and has not got an offset if switching

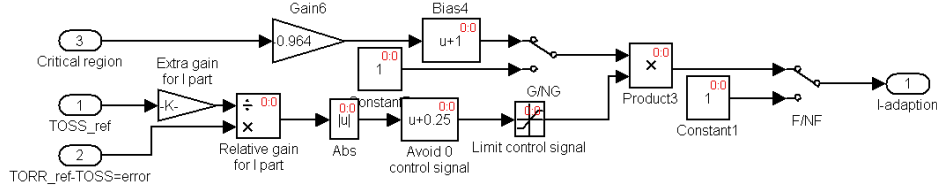


Figure 5.1: The I-adaptive block

between the velocity and droop limit controller. The controller for the droop

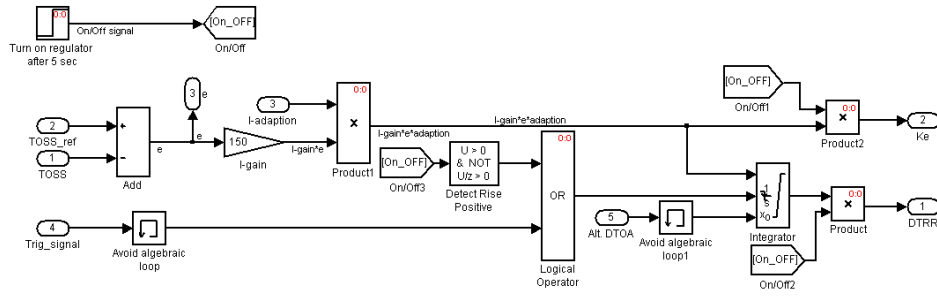


Figure 5.2: Velocity controller

limit consist of an I-part, when in normal operation the droop limit controller is following the velocity controller with a slight positive offset. When the *rpm* drops below the preset droop limit the control starts to regulate on the *rpm* by lowering the gear ratio instead. To obtain a nice and smooth control signal¹ both the integral controllers are reset with the current control signal at the switching points. The result under heavy load of this implementation will be an alternation between the two controllers. The gearbox keeps a constant gear until the droop limit is reached whereupon it starts gearing down. This will result in the speed being significantly lower than requested but a heavier load may be handled instead.

5.2 MicroAutoBox II

When implementing the approaches mentioned in Section 4 on the MAB a few changes were needed. Since the solutions no longer were connected to the rest of the Simulink model their input and output signals needed to be received and transmitted via the CAN local bus. In addition to this, signals and parameters were named to allow for measuring and calibration of the solutions on the MAB, in real time. To avoid reprogramming the MAB when testing different solutions

¹For results of the adaptive controlling see Section 6.

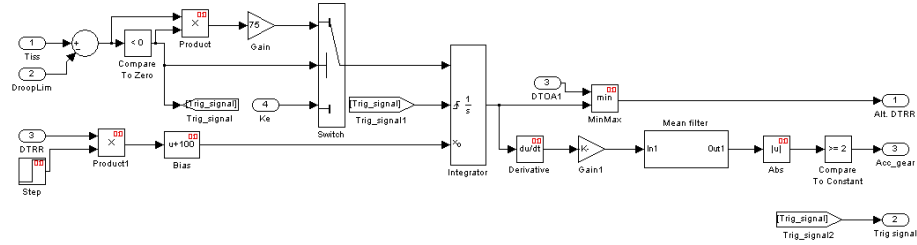


Figure 5.3: Droop limit controller

all solutions were added to the same Simulink model. Switches were therefore added for easy switching between the solutions and to assure that not more than one solution is active at any given time. Explanations of the different parts of this model can be seen below. For more information on how to set up the MAB and download a Simulink model to it, see Appendix A. This guide provides the knowledge needed to use the MAB in the same way as it was used in this thesis.

5.2.1 Communication

In this section the blocks used for setting up the CAN communication and the XCP, Universal Measurement and Calibration Protocol, as well as receiving and transmitting CAN messages are explained. These blocks can be seen in Figure 5.4. To receive and transmit messages on the CAN two types of blocks were used, the CAN controller setup block and the receive/transmit blocks. The CAN controller setup block establishes the necessary settings for communication over CAN. The receive blocks (light green) were used to receive messages from the CAN and the transmit blocks (light red) were used to send a message to the CAN. One block corresponds to one CAN message. The outputs from and inputs to these blocks are the used signals of the messages the blocks corresponds to. The gains and biases are used to scale and offset the signals. For information about the CAN messages, identifiers, signal start bits, lengths etc see Appendix D. A multiport switch was used to switch between the different solutions for adjusting the droop limit. The onoff parameter decides which of these solutions that is active and the onoff input to the CAN transmitter tells the VDC if any droop limit adjustment is active or not. The red box named Constant1 was used to send a constant value to adjust the droop limit. To gain access to the signals and parameters in the Simulink model XCP on Ethernet were used. This means that, with the help of the protocol, a PC connected to the MAB via Ethernet were used to measure and calibrate the signals and parameters on the MAB. To activate this protocol the RTIEth Setup and RTIEthXCP Data Capture blocks were used.

5.2.2 Approaches

The different approaches were implemented in such a way so that the signals and trigger conditions could be altered in real time. Switches with user inputs were added to change between different modes. The important signals were highlighted and named which made logging of them possible. The solutions and how they were implemented are explained in Figure 5.5 to Figure 5.9. In Figure B.5 and B.6 a complete overview of the MAB program can be seen.

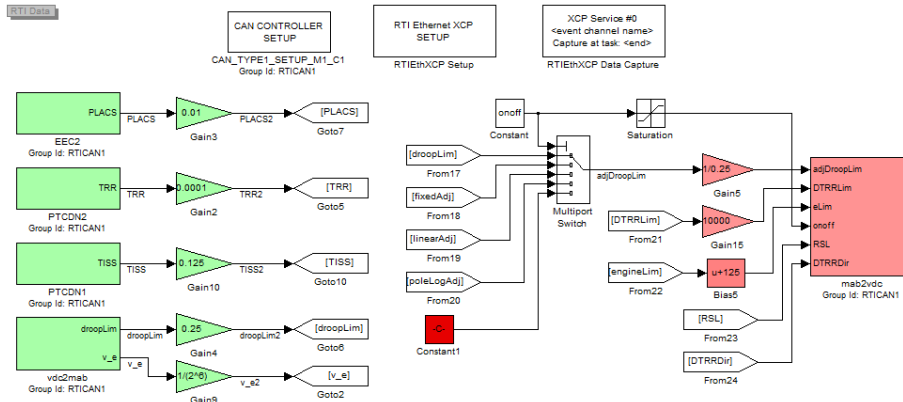
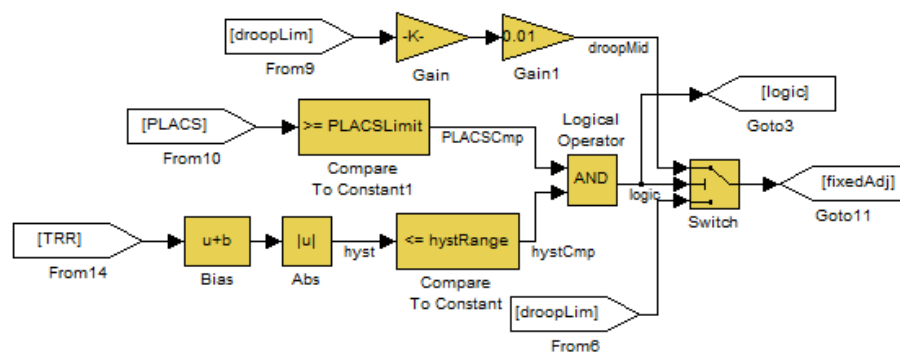


Figure 5.4: The I/O of the program on the MAB.



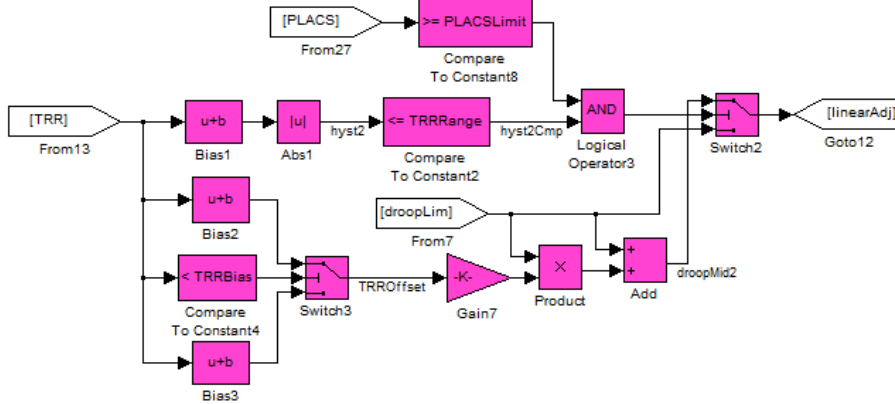
PLACSLimit is used so that the engine is under full load when the adjustment should be active. Corresponds to trigger condition 2 in Section 4.3.

hystRange decides the size of the hysteresis which the adjustment will be active within. Corresponds to the trigger condition 1 in Section 4.3.

The **Bias-block** contains the parameter **TRRBias** which should be set to the value of the gear shifting point.

The **Gain-block** contains the parameter **droopPerc** which is used to decide the size of the droop limit adjustment.

Figure 5.5: The implementation of the fixed droop limit adjustment.



TRRRange decides the size of the hysteresis which the adjustment will be active within. The value is used in the following blocks:

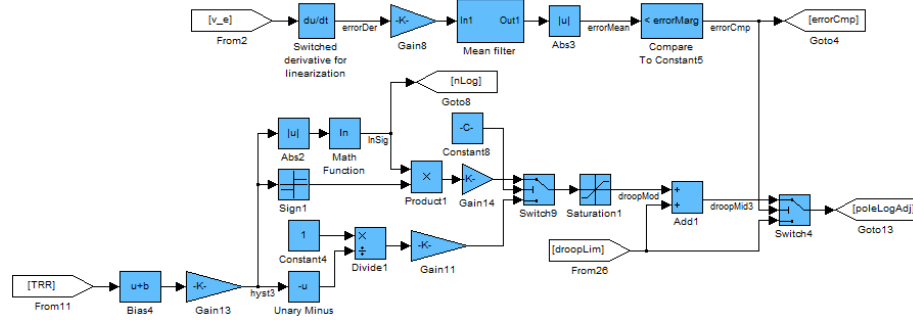
- Bias2
- Bias3
- Compare To Constant2

TRRBias should be set to the value of the gear shifting point. It is used in the blocks:

- Bias1
- Bias2
- Bias3
- Compare To Constant4

Gain7 contains the parameter **TRRImpact** which is used to change the steepness of the linear adjustment.

Figure 5.6: The implementation of the linear droop limit adjustment.



errorMarg is compared to the derivative of the velocity error. If the derivative is larger the droop adjustment is deactivated. Corresponds to the trigger condition 5 in Section 4.3.

TRRBias should be set to the value of the gear shifting point.

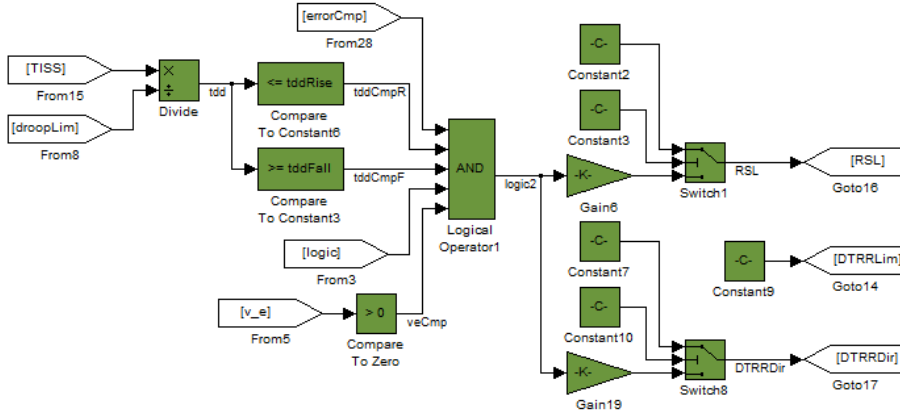
Constant8 contains the parameter **poleOrLog** which is used to change between pole and logarithmic adjustment.

Gain14 contains the parameter **logGain** which is used to change the size of the droop limit adjustment for the log approach.

Gain11 contains the parameter **poleGain** which is used to change the size of the droop limit adjustment for the pole approach.

Saturation1 contains the parameter **poleLogLim** which is used as the upper and lower limit for the size of the adjustment.

Figure 5.7: The implementation of the pole and logarithmic droop limit adjustment.



PLACSLimit is used to tune the trigger condition 2 which can be seen in Section 4.3.

hystRange is used to tune the trigger condition 1 which can be seen in Section 4.3.

tddRise is used to tune the trigger condition 3 upper limit which can be seen in Section 4.3.

tddFall is used to tune the trigger condition 3 lower limit which can be seen in Section 4.3.

errorMarg is used to tune the trigger condition 5 which can be seen in Section 4.3.

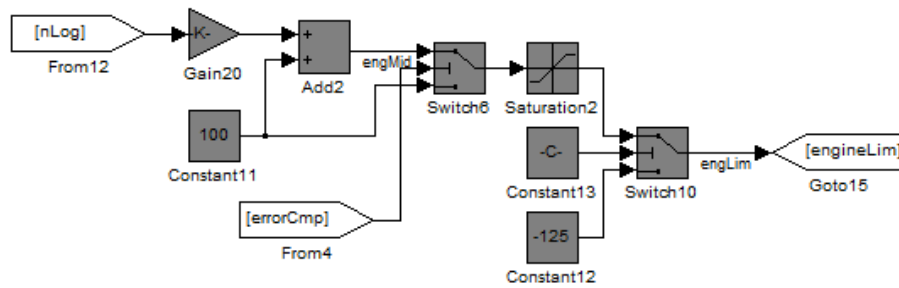
Gain19 contains the parameter **DTRRDirGain** which is used to change, activate and select the desired behavior of the *RSL* solution.

Constant7 contains the parameter **DTRRDirValue** which is used to send a chosen value on the *RSL* solution.

Constant10 contains the parameter **DTRRDirConst** which is used to change between sending *DTRRDirGain* and *DTRRDirValue*.

RSL* corresponds to **DTRRdir*** and works in the same way.

Figure 5.8: The implementation of the *RSL* approach.



errorMarg is used to tune the trigger condition 5 which can be seen in Section 4.3.

Constant13 contains the parameter **engLimActive** which is used to active and deactivate the torque limitation approach.

Gain20 contains the parameter **trqGain** which is used to affect the impact of the logarithmic torque limitation.

Saturation2 contains the parameter **trqSatLow** which is used to declare a lowest limit of the engine limitation.

Figure 5.9: The implementation of the engine limitation approach.

Chapter 6

Simulink model tuning

As mentioned before the problem with alternations between the two gears occur when driving under heavy load with a badly chosen droop limit. This phenomena can be seen in Figure 6.1. It should be noticed that the following plots increase with 10 seconds in i x-axis and 0.1 i_G on the y-axis per vertical/horizontal line. Another problem that can be seen here is that the step response was very

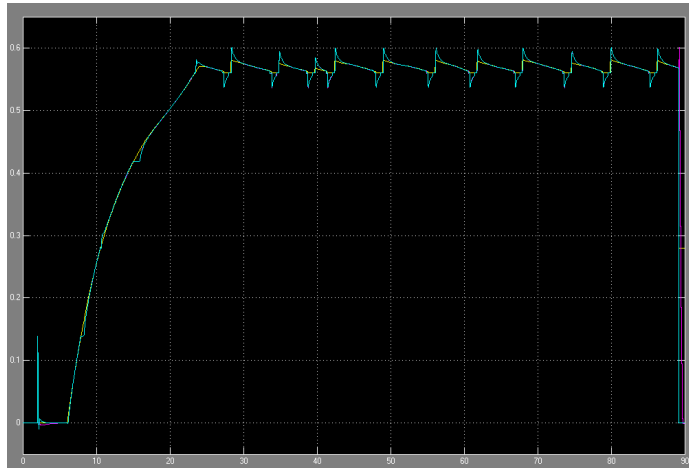


Figure 6.1: Low gain, no gain scheduling for error, no gain scheduling for critical region and no controller/compensation active.

slow, it takes almost 20 seconds from the start of the step until a proper value is obtained. Since the model simulations took quite a long time a lot of tuning was performed to save time. By doubling the control power a much quicker step response was obtained, see Figure 6.2. To handle this aggressive controller in areas where fine/small control actions were needed gain scheduling was applied. First a relative gain scheduling was applied that multiplies the control signal with the ratio of the relative error (error/reference signal). Since the control

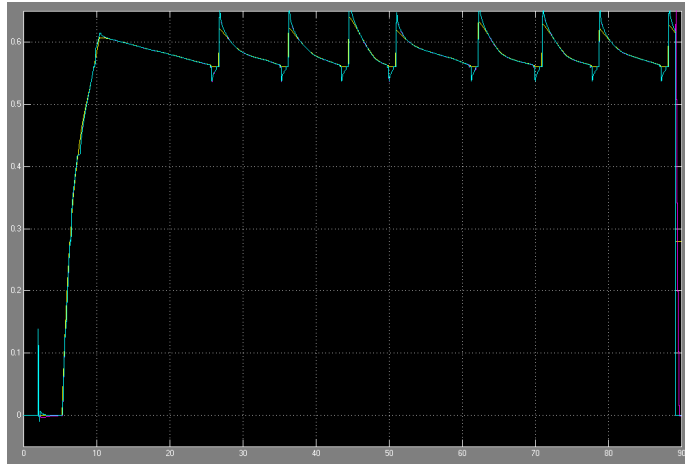


Figure 6.2: Full gain, no gain scheduling for error, no gain scheduling for critical region and no controller/compensation active.

signal gets less aggressive closer to the reference value the control signal can be increased even higher. This gain scheduling helps in regions where the relative error is small and boost the control signal when the error is large. Unfortunately it lacks effectiveness when the desired speed reference is not obtained, i.e. when the engine speed is on the droop limit, see Figure 6.3. This is valid as long as the reference signal is not put at the droop limit. Therefore a second gain

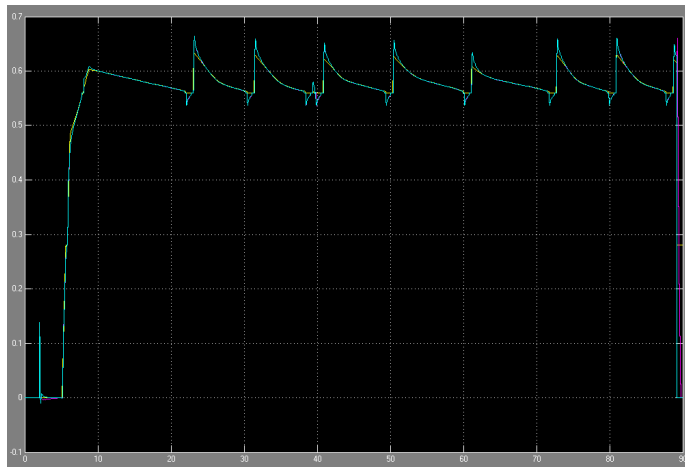


Figure 6.3: Full gain, gain scheduling for error, no gain scheduling for critical region and no controller/compensation active.

scheduling was added that was active in "critical region", this is when possible gear alternation may occur. This gain scheduler simply cuts about 98% of the control signal in the critical region, see Figure 6.4. The effect of this was that the alternation of the reference signal was kept small which resulted in a smoother

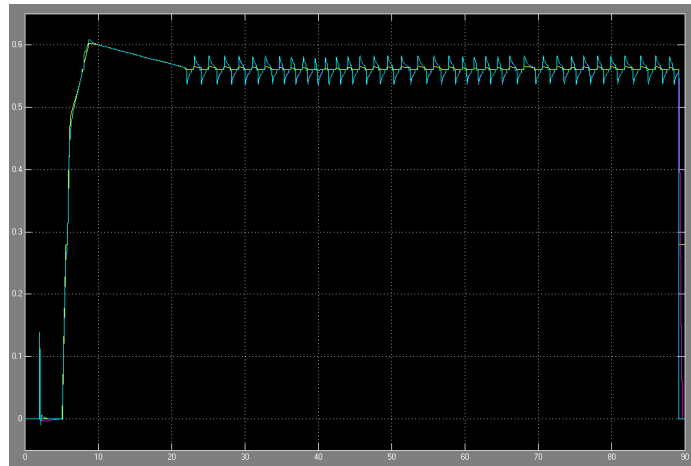


Figure 6.4: Full gain, gain scheduling for error, gain scheduling for critical region and no controller/compensation active

signal. As seen in Figure 6.4 the step response is now only 5 seconds, which shortened the time consumption of the simulations a lot. When the control signal was desirable the alternation between gears needed to be fixed. The simple solution to add a offset to the gear reference signal did not work because the integrator part of the controller simply worked around it and no desired effect was achieved this way. A workaround with an anti-windup was implemented but the jumps that occurred due to the offset were not acceptable and therefore no further investigation was made to this approach. Instead the approach of adjusting the droop limit set by the driver was chosen. If the droop limit is set slightly lower the i_G will be slightly higher and if chosen higher a slightly lower i_G will be obtained.

Chapter 7

Result and observations

7.1 Simulink

7.1.1 Fixed adjustment of the droop limit

The different droop limit adjustments worked quite well in general in the Simulink model, but did not have the same success on the tractor simulator and the real tractor.

3% negative adjustment

When within the critical region the droop limit set by the driver is adjusted to 97% of its value. This allows i_G to become slightly higher and through this action alternation was avoided, see Figure 7.1.

3% positive adjustment

When within the critical region the droop limit set by the driver is adjusted to 103% of its value. This allows the i_G to become slightly lower and through this action alternation was avoided, see Figure 7.2.

7.1.2 Pole sliding adjustment

By continuously adjusting the droop limit by a factor dependent on a pole placed in the gear switching point this critical region will be avoided. In Figure 7.3 negative adjustment by pole sliding to the droop limit can be seen.

7.1.3 Integral adjustment

While in the critical region a small number is multiplied by the sign of the derivative of TRR and then integrated and multiplied by the droop limit. The effect was similar to the fixed 3% offset but grows and decreases smoothly (in theory) instead of jumping between the actual droop limit and the adjusted

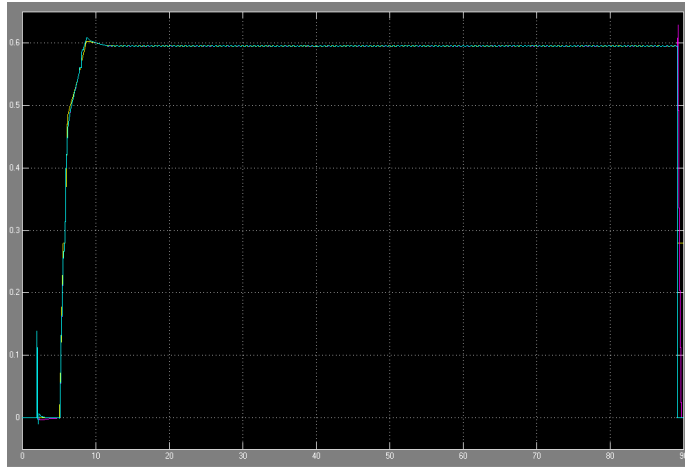


Figure 7.1: Full gain, gain scheduling for error, gain scheduling for critical region and -3% to the droop limit active.

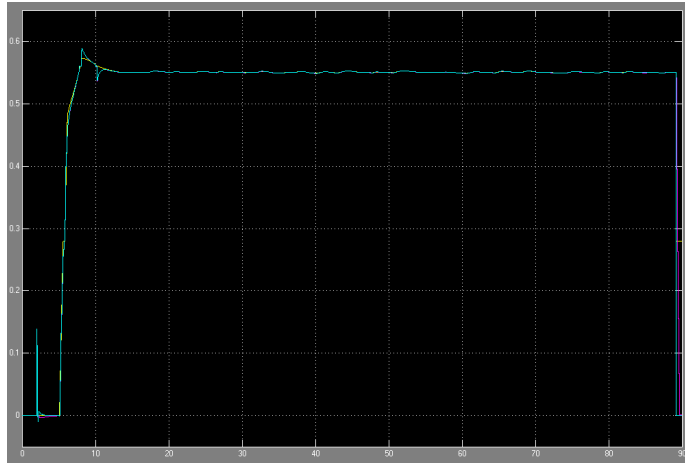


Figure 7.2: Full gain, gain scheduling for error, gain scheduling for critical region and +3% to the droop limit active.

one. The effect can be seen in Figure 7.4. Unfortunately the integral offset alternative was hard to implement in reality. This is since it was dependent on derivatives from signals that were hard to get good values from even though filters were used.

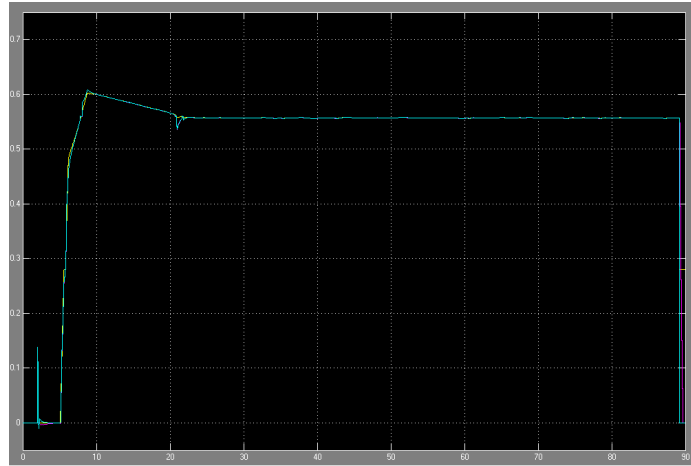


Figure 7.3: Full gain, gain scheduling for error, gain scheduling for critical region and pole sliding to remove gear alternation.

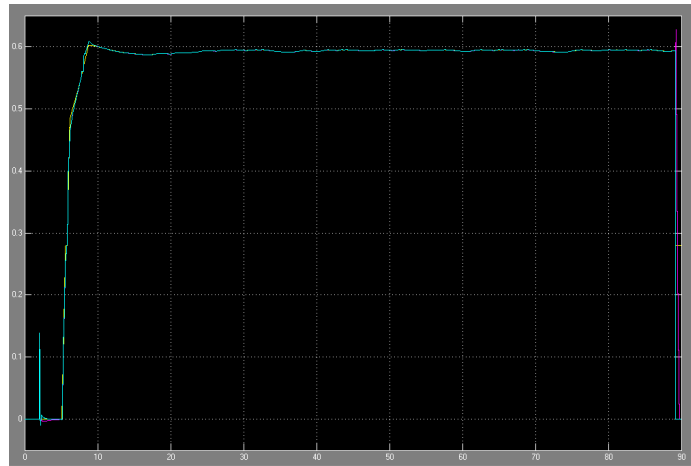


Figure 7.4: Full gain, gain scheduling for error, gain scheduling for critical region and integral offset to remove gear alternation.

7.2 Tractor simulator

7.2.1 Comparison increased/decreased droop limit

When running the droop limit adjustments on the tractor simulator observations were made on when to increase or decrease the droop limit. When under heavier load an increase of the droop limit, and by that lowering the gear, resulted in less gear alternations than decreasing it did. Though under lower load the opposite was observed, a decrease of the droop limit resulted in less gear alternations than an increase did. It should be noted though that the terms heavier and lower load are relative terms and that they both are quite heavy to be able to push the engine to the droop limit. In Figure 7.5¹ the effect that +3% respectively -3% is more effective for heavier respectively lower loads can be seen. Through this comparison the conclusion that an active choice has to be

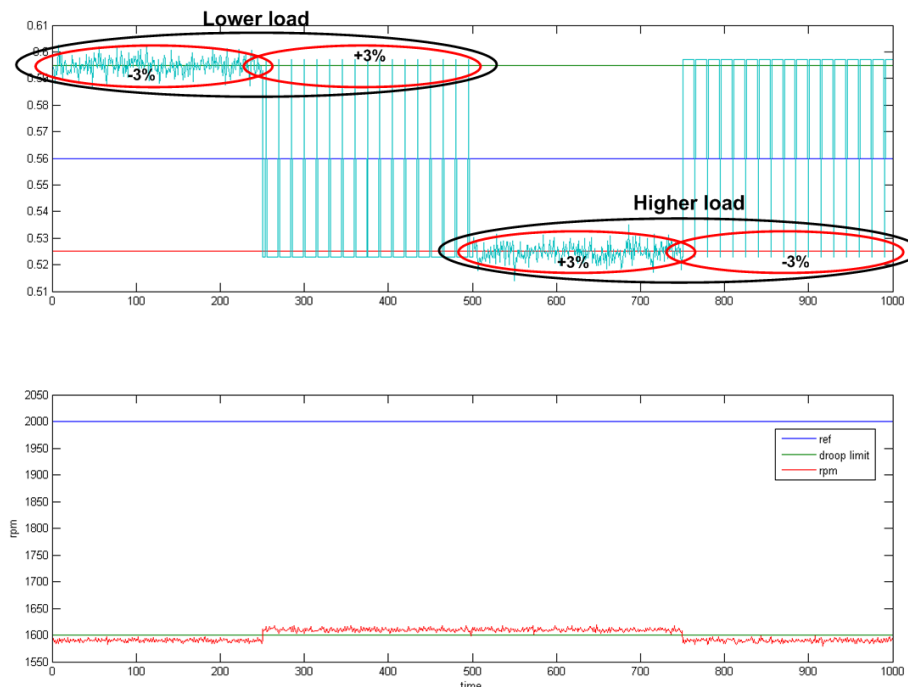


Figure 7.5: Schematic plot of the described phenomena, the top plot shows gear alteration/non-gear alteration. The bottom plot shows the alteration made to the droop limit.

made in real time whether to increase or decrease the droop limit depending on the load. The degrees of freedom of the droop limit approaches were thereby lowered. This led to problems since estimation of the current load is hard and far from accurate, besides, when driving in the field the load is varying a lot. The unlucky case that the loads goes from "low" to "high" within its normal

¹Please not that this plot is a schematic example of the phenomena observed, no measured values were used to create this plot.

alternation would have a devastating effect on the control algorithm. This is since the gear alternation would in fact be increased to the span of the hysteresis i.e. the gear alternation amplitude would in fact increase. In this case a lock down of the gearbox is preferred because then the lower gear may be chosen. By this choice the efficiency loss between the gears can be compensated.

7.2.2 Range shift limitation

The *RSL* showed good result and completely stopped the gear alternation in the tractor simulator. In the simulations the trigger signals that were used to activate the lock was sufficient to break the lock in various situations when the lock down of the gearbox was undesired. One problem that occurs is that small jerks may appear when deactivating the *RSL*, however this may be suppressed by better tuned trigger conditions. The effect of the *RSL* in the tractor simulator can be seen in Figure 7.6.

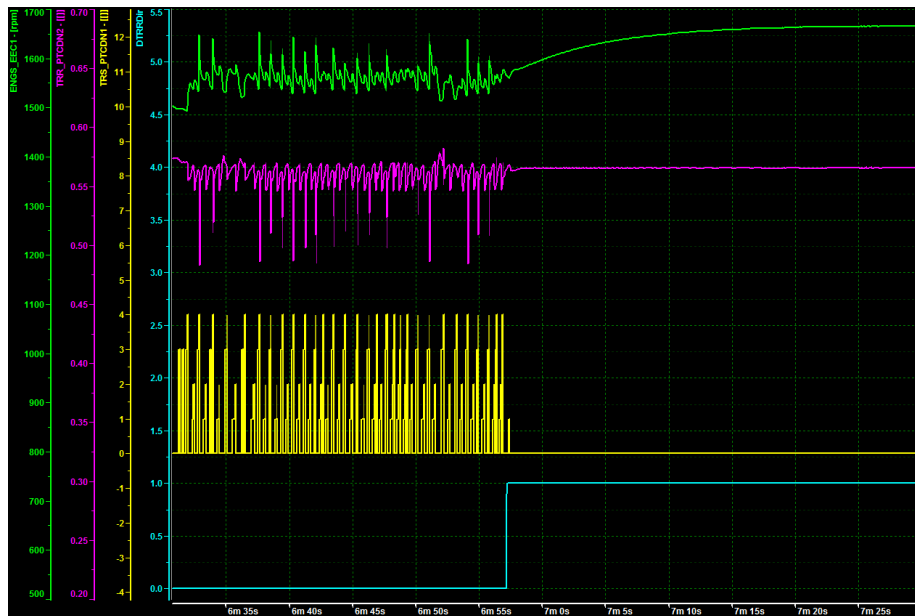


Figure 7.6: *RSL* effect in tractor simulator.

7.2.3 Torque limitation

The torque limitation proved to effectively suppress the gear alternation. However, the solution was only tested on the tractor simulator since the torque limitation was not yet implemented in the Simulink model nor did the Xerion 5000 have a engine that supported torque limitation. The torque limitation suffers from a problem with the trigger signals, though. If the unlikely scenario

occurs that the load is slowly decreasing the torque limitation would not be broken. This resulted in limitations in regions where limitations were not needed. Since the real tractor did not have the option to limit the torque of the engine this approach was not further investigated even though it shows good potential to handle the problem. If the approach was to be used a need for a better trig signal is a must.

7.3 Tests on Xerion 5000

The different tests performed on the Claas Xerion 5000 were documented in a journal that is attached to this report in Appendix C.

7.3.1 Positive or negative adjustment of the droop limit

It was observed that an active choice has to be made regarding a positive/negative adjustment of the droop limit. This observation was also made in the tractor simulator and thereby strengthened the theory. The effect is shown in Figure 7.5. After this some thoughts of load estimation occurred but was quickly discarded, since load estimation is quite tricky. Instead approaches of trying to stay on the side of the switching point that the *TRR* currently is located on. This idea led to version 2 of the pole adjustment of the droop limit. By not having an absolute value function different alternations will be performed depending on from which direction *TRR* approaches the gear shifting point.

7.3.2 Pole adjustment

The pole adjustment successfully suppress most of the gear alternation, some alternation pass through most likely due to the engine oscillations explained in Section 7.3.4. The adjustment made to the droop limit was of the same size as calculated in Example 1. This can be seen in Figure 7.7

7.3.3 Range shift limitation

Since the *RSL* signal that existed on the VDC suffered from an anti-windup problem a firmware update that locked the reference signal to the gearbox, *DTRR*, was implemented. This limitation could be used in a similar way as the *RSL* signal and therefore replaced it in the implementations. The range shift limitation had a major effect on the gear alternation and proved to sufficiently suppress the problem. The criteria mentioned in Section 4.3 seemed to have good potential. With some tuning this method could possibly solve the gear alternation problem, at least according to the results acquired on the test track.

To lock the gearbox in the lower gear seemed to achieve a better result than the upper gear. A lock in the upper gear may work in some cases, however since the efficiency is lower the ability to handle a large load is better in the lower gear and therefore a lock down in the lower gear is preferred. The reason

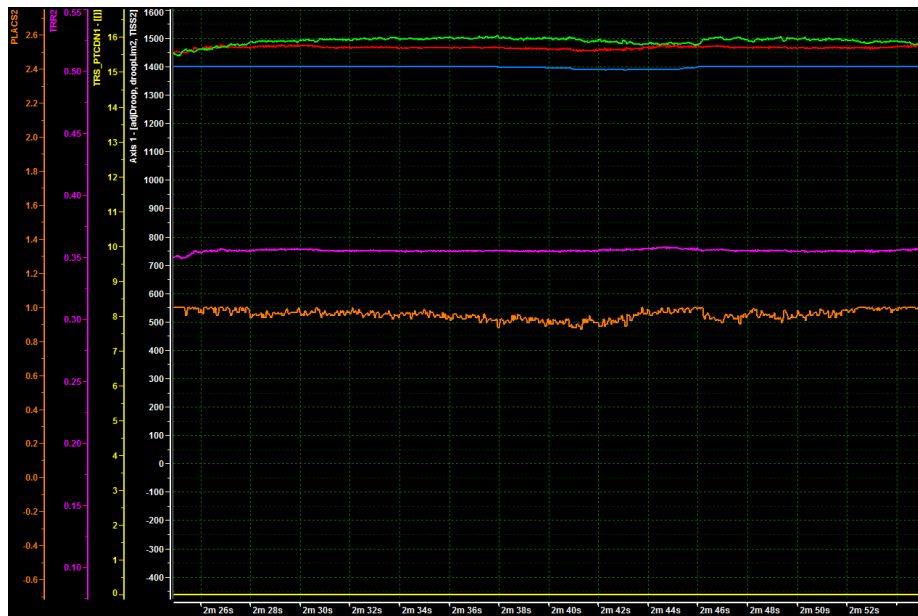


Figure 7.7: How pole adjustment affects the gear alternation on the real tractor. The droop limit is pushed slightly higher which keeps the gear ratio TRR just below the shifting point 0.37..

why it did not always work to lock in the upper gear is due to a safety function implemented in the VDC that allowed gearing down even when a lock down was made. In Figure 7.8 the result from a test drive on the tractor can be seen. In that figure the tractor is driven for a little more than 3 minutes whereupon the *RSL* is activated and with that the gear alternation suppressed. At first

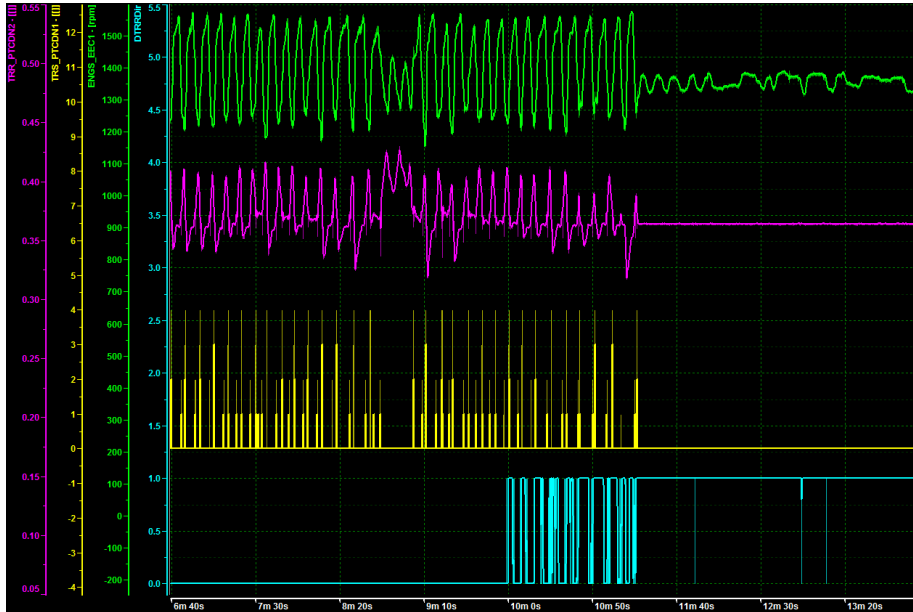


Figure 7.8: How *RSL* affects the gear alternation on the real tractor. *RSL* was activated at 10 min and some tweaking of the trigger conditions were performed whereupon the alternation stopped.

the *RSL* has no effect on the gear alternation but after a minute of criteria tweaking it successfully suppresses the alternation. The lack of effectiveness in the beginning occurred since the *PLACS* dropped before each gear change while the criterion *PLACS* should be above 98% percent, see Figure 7.10 for the effects of the drop. How the transmission ratio, *TRR*, is locked under a chosen limit can be seen in Figure 7.9. With a closer look it can be seen that the *TRR* sometimes peaks above the limit, this is due to influences from the clutches. This is the reason why the limit is set to 0.365 instead of the switching point 0.37.

7.3.4 Engine load drop

During the tests on the real tractor it was observed that the engine load dropped before each gear alternation. The reader should notice that this effect occurred both when the suggested solutions were and were not active. This created a bit of a problem since one of the criteria that triggers the different solution was

that the engine load should be close to 100%. The best explanations for this problem was that the velocity controller was poorly tuned for driving with the brake trailer. In Figure 7.10 the following signals can be seen:

- The speed reference to the engine, *RSSL*. (Red)
- The droop limit. (Blue)
- The engine speed also know as the transmission input shaft speed, *TISS*. (Green)
- The state of the gearbox (shifting or no shifting), *TRS*. (Yellow)
- The gear ratio of the gearbox, *TTRR*. (Purple)
- The engine load, *PLACS*. (Orange)

From this picture the conclusion can be drawn that the velocity controller is not perfectly tuned for the tractor with the brake trailer. This resulted in the engine speed reference alternating which led to the alternation of the other signals. When the *PLACS* criterion was removed as a trigger signal the different solutions were active at the right times.

RSL

The *RSL* solution effectively suppresses the gear alternation even though the whole system (engine speed reference, engine speed and *PLACS*) oscillates. It all so had the appreciated effect that all these oscillations were decreased in amplitude. The Figure 7.11 is equal to Figure 7.10 except that the *RSL* was active.

Pole adjustment

The pole adjustment also had a good effect on the engine oscillations and suppressed the gear alternation in a satisfying way. This can be seen in Figure 7.12, the colors are explained in the list below:

- The adjusted droop limit. (Red)
- The droop limit. (Blue)
- The engine speed also know as the transmission input shaft speed, *TISS*. (Green)
- The state of the gearbox (shifting or no shifting), *TRS*. (Yellow)
- The gear ratio of the gearbox, *TTRR*. (Purple)
- The engine load, *PLACS*. (Orange)

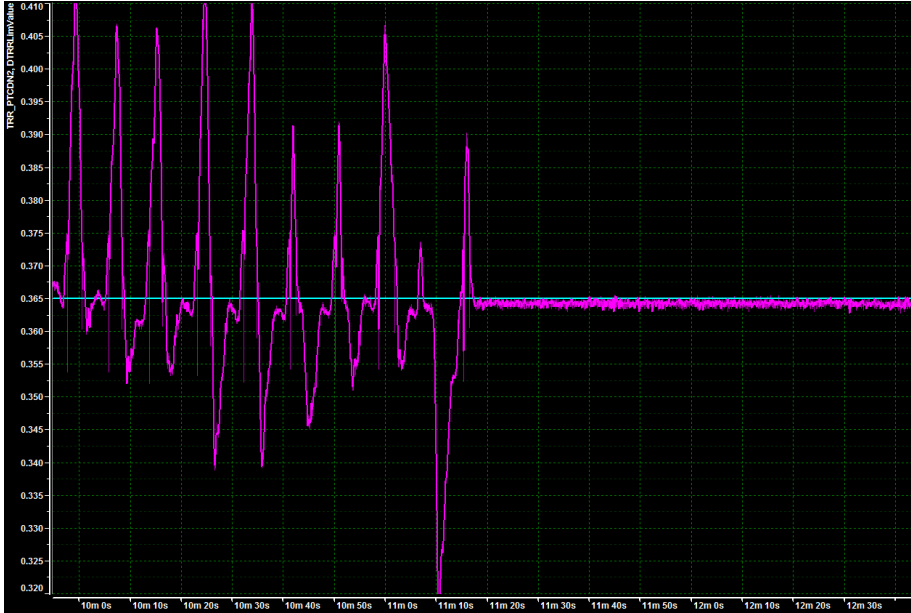


Figure 7.9: The TRR stays below the $DTRR$ limitation when RSL is active.

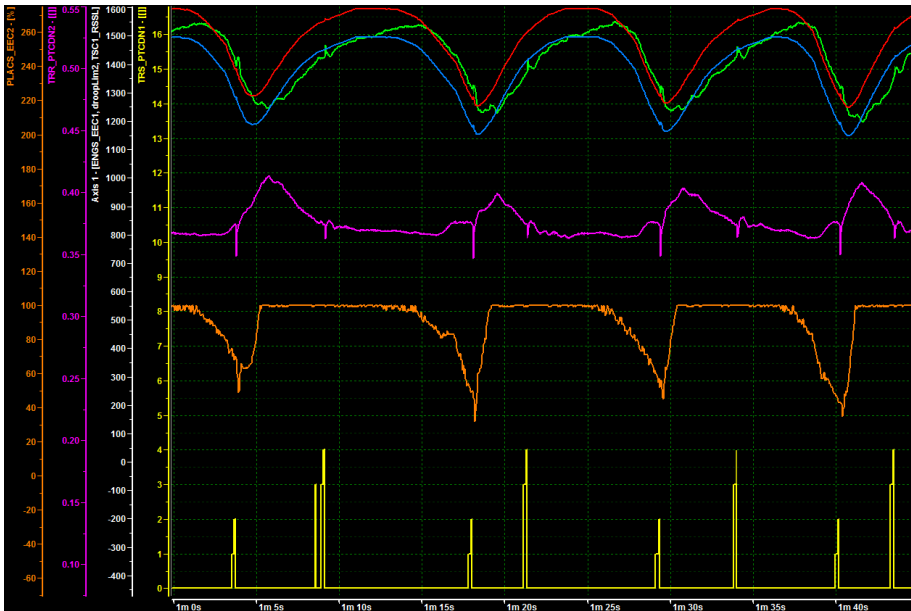


Figure 7.10: The effect of the badly tuned velocity controller.

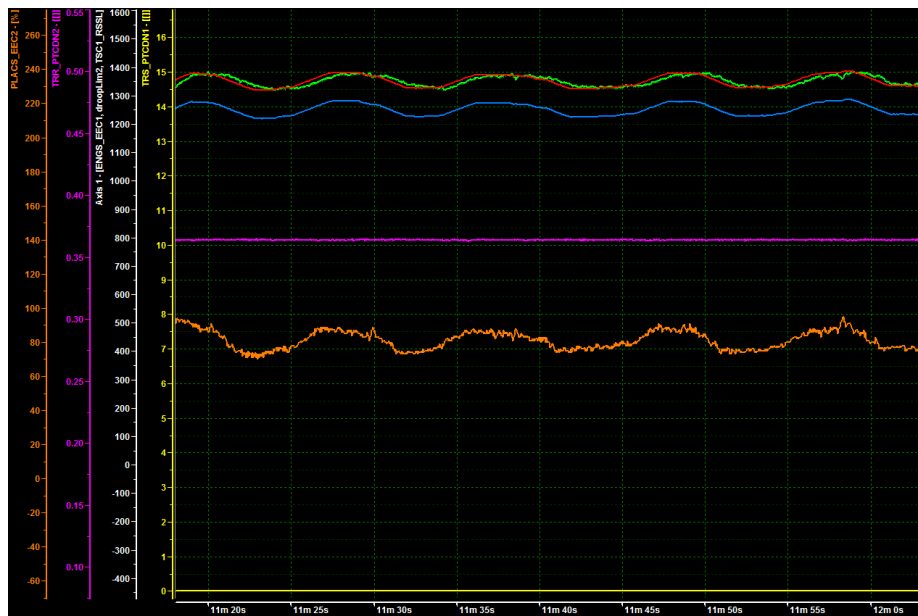


Figure 7.11: The effect of the *RSL* on the badly tuned velocity controller. As seen the *RSL* have both a positive effect on the gear alternation as well as the engine oscillation.

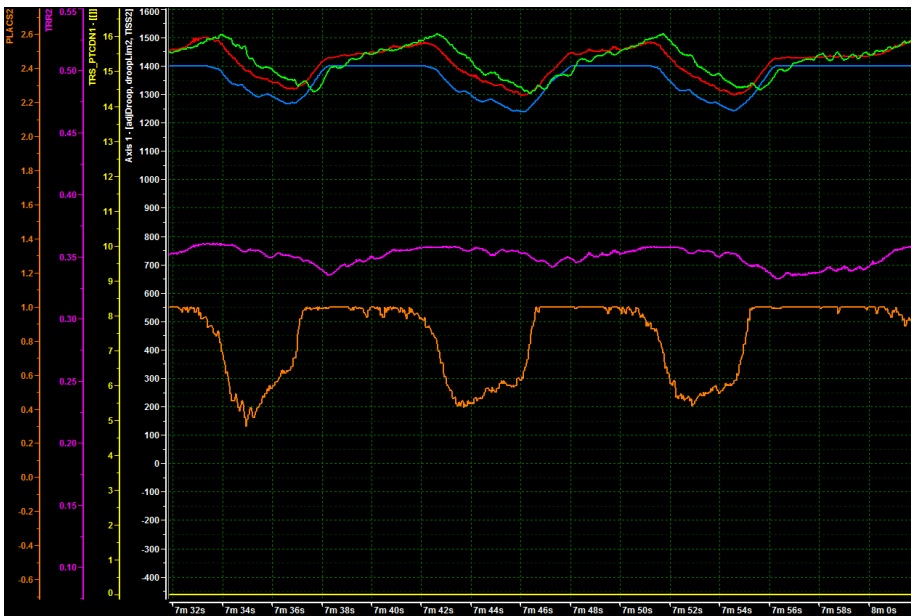


Figure 7.12: The effect of the pole adjustment on the badly tuned velocity controller. As seen the pole adjustment had both a positive effect on the gear alternation as well as the engine oscillation. However the effect was not quite as good as the *RSL* effect.

Chapter 8

Conclusions

The three different approaches (droop limit adjustment, RSL and torque limitation) are evaluated in the Table 8.1.

8.1 Droop limit adjustment

The droop limit adjustment suffers from the choice to increase or decrease the droop limit. This choice should be made with consideration to the load, which makes it tricky since the load is rather hard to estimate. However, if a good estimation was to be found the method shows good potential to remove more alternations than in its current state. The large advantage of this approach is the simplicity due to the few degrees of freedom.

8.2 Range shift limitation

Range shift limitation successfully removes gear alternation but the high amount of degree of freedom requires a lot of tuning. The idea of locking the gearbox may not be desirable by all drivers since it limits the driving freedom and may cause small jerks when deactivating the lock-down. This approach is the one that shows the highest potential at its current state and is therefore recommended by the authors of this thesis.

8.3 Torque limitation

This approach has great potential, however, it suffers from two major drawbacks. One is that not all the engines have the possibility to limit the torque. The other is that so far no sufficient trigger conditions have been found. The great potential comes from the ability to successfully suppress gear alternation without affecting the driver settings. Though, as in the range shift limitation some drivers might not like the idea of limiting the engine.

	Droop limit adjustment	Range shift limitation	Torque limitation
Violations of driver settings	Deviations from the set droop limit will occur.	The <i>rpm</i> wanders off with the same size as the droop limit is pushed in the droop limit approach.	No modification will be noticed on the <i>rpm</i> .
Possibility to implement as a shift recommendation in TCU	Not in current state. The droop limit signal and the trigger signal is required and they are only available in the VDC.	Not in current state. The trigger conditions requires a signal only available in the VDC. An anti-windup in the VDC is required as well.	Unknown since no satisfying conditions were found.
Negative effects on driving experience	The droop limit is shifted.	Small delays will occur when exiting the locked region which may give jerks.	The vehicle may feel limited in its power.
Complexity of solution	Only triggers on one signal thus the less complex solution.	Have several triggering signals, all of which needs to be individual tuned.	Trigger signal(s) need to be found. Not all engines have torque limitation as a possibility.
Possibility to handle large efficiency drops at switching points	The droop limit will have larger adjustment of the efficiency jump is larger.	The rpm will wander further off if the efficiency jump is larger.	The efficiency jump don't effect this solution in a major way.
Level of gear alternation suppression	Removes some gear alternations.	Successfully removes the alternations.	Successfully removes the alternations.

Table 8.1: Comparison of methods.

Chapter 9

Future work

In the list below ideas for future work can be seen.

- Find trigger condition for the torque limitation approach since it showed good potential.
- Investigate how large percentage of the ECCOM customers that have an engine with torque limitation to evaluate its potential value.
- In the future when the VDC has got a larger calculation capacity the possibility to use an optimal controller should be investigated. Good models of the process have already been created so in the future these models could be used in the optimal controllers such as MPC¹ or LQR². The models used in the optimal controller should take the gear efficiency table into account as well as the torque output of the engine.
- Conduct a field test drive to validate the conclusions from this thesis.
- Find alternative trigger conditions to allow implementation of the solutions in the TCU rather than the VDC.
- Develop a load estimator to enable more accurate decisions regarding the choice of the second or third gear. The load estimation could be included in all the approaches. It could also be included in the future optimal controller to have an optimization that takes the load into account.

¹Model predictive control.

²Linear quadratic control.

Appendix A

A short guide to MicroAutoBox II

A.1 Introduction

This guide explains how MicroAutoBox II and the programs related to it were set up for the project described in report *Reduction of undesired range shifting in an agricultural CVT*. The MAB that was used contained a DS1401 base board and a DS1507 I/O board. Besides MicroAutoBox II, the following hardware and software were used:

- Matlab R2009bSP1 and Simulink
- ControlDesk Basic Version 3.7.1, Real-Time Workshop 6.7 and TargetLink 3.1 from dSPACE
- CANcaseXL log, CANalyzer 7.6.84 and CANape 10.0 from Vector
- USB-Ethernet adapter¹

It is assumed that the above software is installed properly on the computer that is to be connected to MicroAutoBox II. It should be noted though that the installation of Real-Time Workshop and TargetLink caused a lot of problems for the authors of this guide. If the reader has problems with this as well, Section A.7 comment 1 might be helpful. Other versions of the software might work as well, but some of the steps in this guide may differ. It should also be noted that the used computer was running on Windows 7.

The guide starts with the hardware (CANcaseXL log and MicroAutoBox II) connections and then explains every step of creating a Simulink model to testing it on the MicroAutoBox II, including software configurations. It focuses on setting up XCP² on CAN (with the CANcaseXL log device) and then explains

¹The benefit of using an adapter is that the computer may stay connected to the company's network while connected to the MAB.

²Universal measurement and calibration protocol

how to adjust the settings for XCP on Ethernet (TCP/IP and UDP/IP). Furthermore, during the whole guide, it should be kept in mind that all components using the CAN must be set to the same baud rate to be able to communicate correctly with each other. The default baud rate is usually 500 kBd by default, but this guide will use 250 kBd.

A.2 Connecting the hardware

For the connection between the MicroAutoBox II and the computer to work the TCP/IP protocol for the USB-adapter³ and the Peer-to-Peer connection has to be set. For this, administrator rights are required. It might be a good idea to write down the previous TCP/IP configurations to be able to restore them later on. These steps can also be found in [9], page 116 – 119.

1. Go to **Control Panel** ⇒ **Network and Internet** ⇒ **Network and Sharing Center**.
2. Open the **Local Area Connection Status**-window by clicking on **View Status of Local Area Connection**.
3. Click on **Properties**.
4. Select **Internet Protocol Version 4 (TCP/IPv4)** and click on **Properties**.
5. **Select Use the Following IP address** and enter *192.168.140.3* in the **IP address** field and *255.255.255.0* in the **Subnet Mask** field according to figure A.1.
6. Close all opened windows by clicking on **OK** when possible and **Close** when not.
7. Restart the computer if asked for.
8. If the computer is already a part of an existing network, switch the computer off and disconnect the network.
9. Connect a cable with a USB/Ethernet adapter to **Host PC** on MicroAutoBox II and a USB port on the computer.
10. Connect $\approx 12\text{-}14$ V to **Power** on MicroAutoBox II and turn the computer back on. More information on connecting the power can be found on page 96 in [9].
11. Open a **Command Prompt** (open the Start menu and search for cmd).
12. In the Command Prompt enter `ping 192.168.140.1` (which is the default IP address MicroAutoBox II)

³External network card connected by the USB interface.

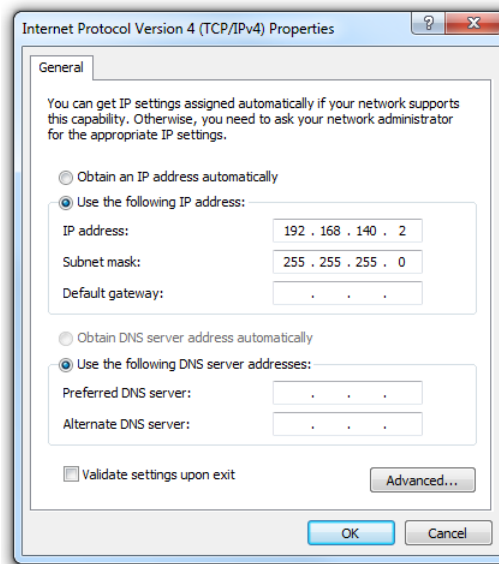


Figure A.1: Settings for the internet protocol. Here .2 is used at the end of the IP address. It is possible to use any ending between .2 and .254 but if DCI-GSI⁵ is also connected note that its default IP address is 192.168.140.2.

13. If you receive a reply from 192.168.140.1 (i.e. *"Reply from 192.168.140.1: bytes=32 time<10ms TTL=64"*) then the connection is ready for use, see Figure A.2.

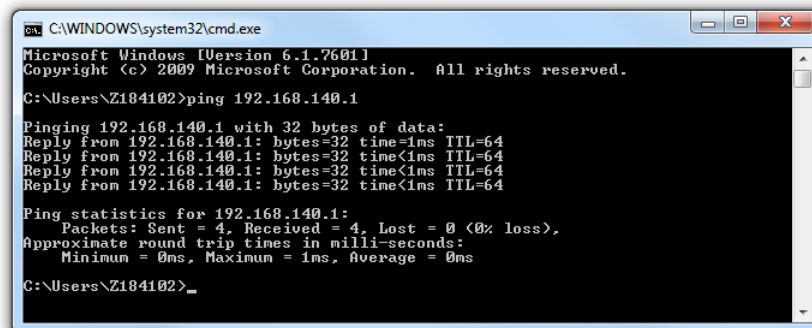


Figure A.2: Desired answer when pinging the MicroAutoBox II.

To connect the CANcaseXL log with the MicroAutoBox II and the computer, connect a cable between **USB** on CANcaseXL log and a USB port on the

⁵Generic serial interfaces.

computer. Then connect the **DS1507 I/O Connector** on MicroAutoBox II to a channel on CANcaseXL log. A $120\ \Omega$ resistor needs to be placed between the cable and the CANcaseXL log channel, this does not apply for the real tractor or the tractor simulator. The connection is now complete.

A.3 Creating a Simulink model

When starting Matlab the *Select dSPACE RTI Platform Support*-window will appear if Real-Time Workshop is installed. Select the option corresponding to the MicroAutoBox II, in this case **RTI1401**. Then, when the start-up configurations are done, enter *rti* in the command window. This opens a window for access to the Real-Time Interface blocks, see Figure A.3. By clicking on **Blocksets** \Rightarrow **RTI CAN Blockset** the blocks for CAN-communication are found, see Figure A.4. From here, the necessary blocks for CAN-communication can be found. These are as follows:

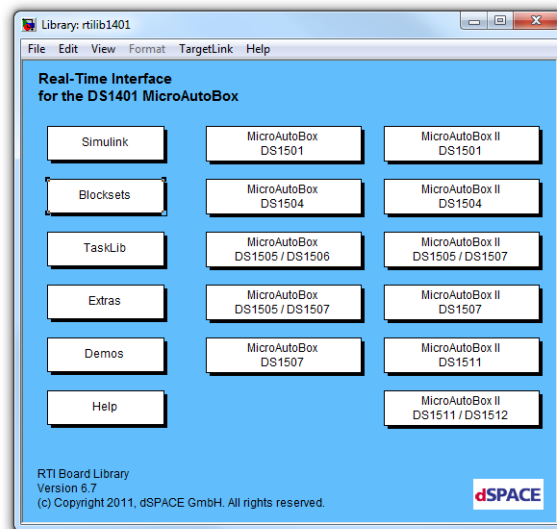


Figure A.3: The library for Real-Time Workshop.

- **RTICAN Transmit (TX)** is used for sending a message from the Simulink model to the CAN. The signals to be sent in the CAN message are the inputs to the block. The outputs of the block do not need to be connected. Inside the block the message name, identifier and length can be specified as well as the message composition, i.e. which bits of the message corresponding to which input of the block. Adding more signals creates more inputs to the block.

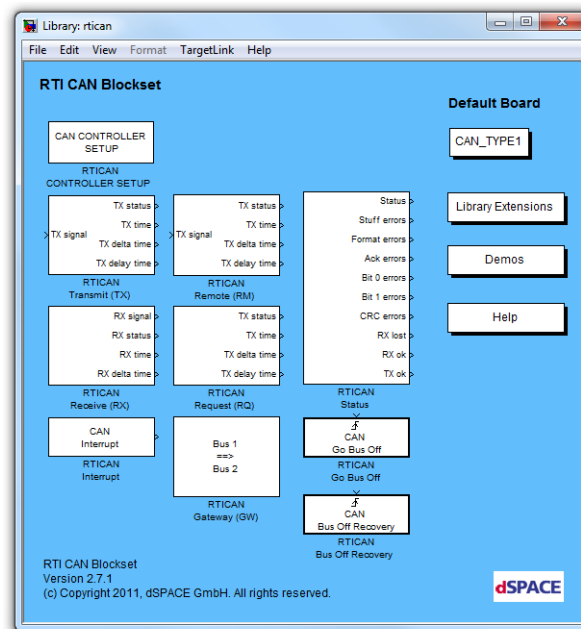


Figure A.4: Blocks for utilizing RTI on CAN. This window can also be accessed by entering *rtican* in the Matlab command window.

- **RTICAN Receive (RX)** is used for receiving a message from the CAN to the Simulink model. Inside the block the message name, identifier and length can be specified as well as the message composition, i.e. which bits of the message corresponding to which output of the block. The only outputs that need to be connected are the signals of the CAN message that are to be used, i.e. the outputs corresponding to the desired signal names defined in the block. Adding more signals creates more outputs to the block.
- There must be at least one **RTI CONTROLLER SETUP** in the Simulink model to be able to use any of the RTICAN blocks. This block specifies the CAN configurations and each Transmit and Receive block must be associated with one of these blocks. There are no input or output signals for this block.
- The **RTICANXCP data capture** block is found by going to *Library Extensions* \Rightarrow *XCP Support* or by entering *rticanxcp* in the Matlab command window. This block is used for data acquisition with XCP on CAN, i.e. to access signals and parameters in the Simulink model on the hardware. There are no input or output signals for this block.

With this information the desired Simulink model for CAN communication can be constructed in the following way:

1. Add a RTI CONTROLLER SETUP block for each CAN controller to be used (more than one Receive and/or Transmit block can be associated with each CAN controller), this guide uses one of this block.
2. Double-click on the block to access its options.
3. Edit the *baud rate* in the *Unit*-tab
4. Activate *Enable XCP support* in the *XCP*-tab.
5. Add a Transmit/Receive block for each CAN message to be transmitted/received by the model.
6. Double-click on the block and edit (or take note of) the *RX message parameters* in the *Message*-tab
7. Add the desired signals for the CAN message in the *Message Composition*-tab. Figure A.5 shows an example of this tab.
8. Add a RTICANXCP data capture block to the model.

To be able to access signals and parameters on the MicroAutoBox II they need to be identified in the Simulink model before it is downloaded to the MicroAutoBox II. How to do this is explained in the first part of Section A.5.2.

A.4 Downloading a Simulink model to MicroAutoBox II

Before downloading the model to the MicroAutoBox II the connection between the MicroAutoBox II and the computer needs to be established. First make sure MicroAutoBox II is powered and connected as described in Section A.2. Then complete the following steps:

1. Open the *Start* menu \Rightarrow *All Programs* \Rightarrow *dSPACE Tools* \Rightarrow *dSPACE ControlDesk 3.7.1* and click on *dSPACE ControlDesk 3.7.1*.
2. Go to *Platform* \Rightarrow *Change Connection...*
3. Select *Network connection* and enter the default IP address for MicroAutoBox II, *192.168.140.1*, according to Figure A.6.
4. Click on *OK*.
5. The *Log Viewer* should now say that the connection to the network client is completed.

A.4. DOWNLOADING A SIMULINK MODEL TO MICROAUTOBOX II 77

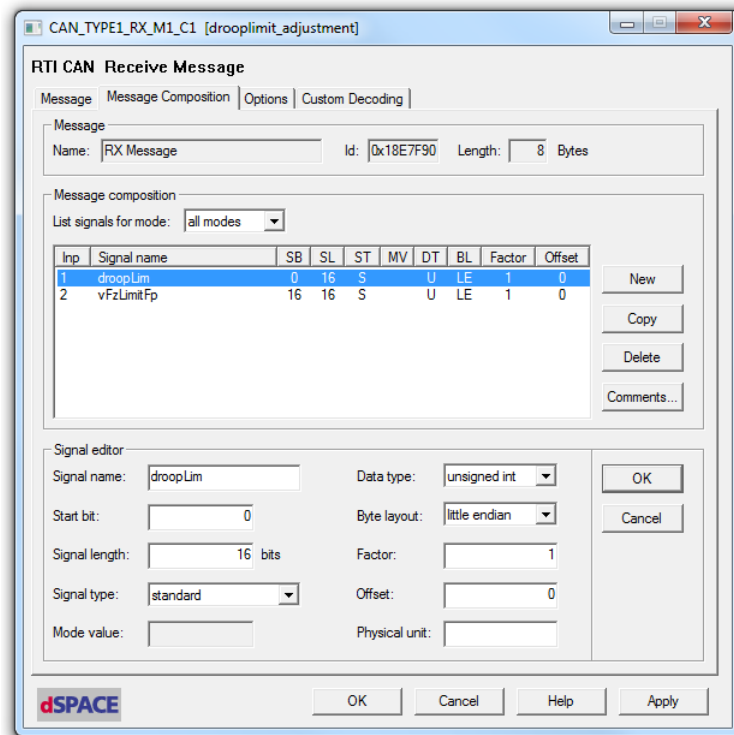


Figure A.5: Example of a CAN message received by the Simulink model containing two signals.

There are also a few configurations to be made in the Simulink model. Go to **Tools** ⇒ **Real-Time Workshop** ⇒ **Options...** in the window for the Simulink model and make the following changes:

- Go to **Optimization** and activate **Inline parameters**.
- Go to **Data Validity** and change **Signal resolution** to **Explicit and implicit**.
- Go to **Real-Time Workshop** and add `-aASAP2ParamAutoGenerate=1 -aASAP2SignalAutoGenerate=1` to the **TLC options** line so that it says `-aGenerateASAP2=1 -aASAP2ParamAutoGenerate=1 -aASAP2SignalAutoGenerate=1` as in Figure A.7.
- If the model is to be downloaded to the Flash memory, so that it stays on the MicroAutoBox II even if the power is turned off, go to **RTI load options** and activate **Load to Flash memory**.

Now, click on **OK** and go to **Tools** ⇒ **Real-Time Workshop** ⇒ **Build Model** to download the model to the MicroAutoBox II.

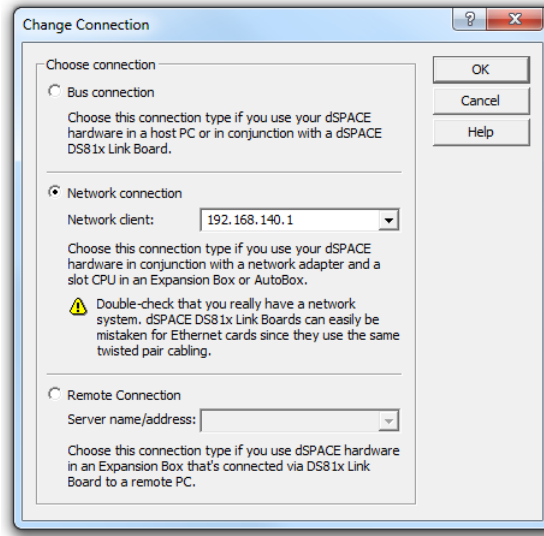


Figure A.6: Settings for establishing a connection between the MicroAutoBox II and the computer.

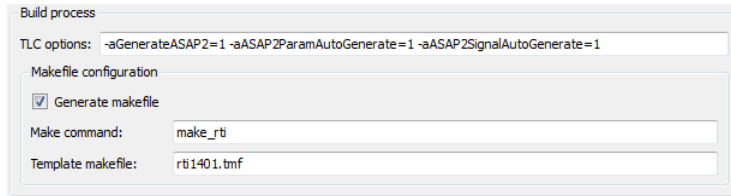


Figure A.7: Settings for the Real-Time Workshop build process.

A.5 Using CANalyzer and CANape

Before using CANalyzer and CANape they must be added to the Vector hardware. This is done by completing the following steps:

1. Go to the *Control Panel* ⇒ *Hardware and sound* ⇒ *Vector Hardware*.
2. In the left menu of the *Vector Hardware Config*-window open *Hardware* ⇒ *CANcaseXL log 1*.
3. Right-click on one of the *CANpiggy 251mag (Highspeed)*.
4. Choose the program and CAN to be used, i.e. *CANalyzer* ⇒ *CAN 1* and *CANape* ⇒ *CAN 1*.

A.5.1 CANalyzer

Start with editing the baud rate by going to the *Configuration* window at the bottom of the CANalyzer window, then double-click on *the chip* at the left. From there, select the CAN used and change the *baud rate*. When the program is ready, click on the lightning symbol named *Start* to activate CANalyzer. It can then be stopped by clicking on the red symbol named *Stop*.

To view messages on the CAN, open the *Trace* window. Here, all messages on the CAN will be displayed. The list can be expanded or compressed by clicking on the *Toggle display mode* button (symbolized by a document with an orange arrow pointing downwards). The continuously updating list can be paused by clicking on the *Pause* button.

The following steps explain how to create a message that are to be sent on the CAN:

1. Right-click on the *blue square* going towards the SEND-symbol in the *Configuration* window.
2. Select *Insert Interactive Generator Block*.
3. Double-click on the newly created *IG*.
4. Click on *New* to create a CAN message.
5. Enter an identifier and the desired value on each byte (and change the Channel and message length (DLC) if required). Note that the identifier for a message in CANalyzer has to be the same as the message identifier in the RTICAN Receive (RX) block for the block to be able to receive the message. The bytes in the message also have to correspond to the bytes of the desired signal in the RTICAN Receive (RX) block.
6. To send a message, either click on *now* to send it once or activate a suitable cycle time to send it continuously.

Read Section A.7 comment 3 before sending or viewing messages exceeding one byte.

A.5.2 CANape

To gain access to signals or parameters in CANape, they must be initialized in the Simulink model before downloading it to the MicroAutoBox II.

- For a signal, this is done by right-clicking on the *line of the signal*, selecting *Signal Properties...*, entering a name in the *Signal name* field and clicking on *OK*.
- For a parameter, enter the *block with the parameter* and change the value to a name and click on *OK*. Then go to the *Matlab command window* and assign a value with the same name.

By doing this, the name of the parameter and the assigned value should be displayed in the Matlab workspace. After building the Simulink model, the named signals should also be displayed in the Matlab workspace.

Enter CANape and do the following initializations:

1. Go to **Device** \Rightarrow **New from Database...**
2. Find the \langle simulink model name \rangle .a2l file and **Open** it. This file is created when building the simulink model and should be located in the folder path that were active in Matlab when the model was built.
3. Select **OK** on the windows popping up, thereby uploading the data from MicroAutoBox II to CANape.
4. Go to **Measurement** \Rightarrow **Measurement Configuration...** \Rightarrow **Edit** \Rightarrow **Insert signal**.
5. From the list, select the desired signals and parameters by marking them and clicking on **Apply** (or double-clicking on them).
6. Close the windows and accept the changes if asked.

Now the setup is done and it's possible to add windows to view signals and change parameters in the following way:

1. Go to **Display** \Rightarrow **Display windows** \Rightarrow **Graphic window** to add a graphic window. The graphic window shows a graph of the desired signals.
2. To add one or more signals to the window, right-click inside of it and go to **Insert** \Rightarrow **Insert measurement signal...**
3. Add the signals to be viewed from the MicroAutoBox II by selecting them and clicking on **Apply**.
4. Right-click in the window again and go to **Configurations...** Here it's possible to for example change axis scaling for each individual signal in the window.
5. If desired, add other kinds display windows to get a different view of the signals.
6. To change a parameter in the MicroAutoBox II go to **Display** \Rightarrow **Calibration windows** \Rightarrow **Calibration window**.
7. Select a data source if asked.
8. Add the desired parameters to be changed by selecting them and clicking on **Apply**.
9. In the new calibration window, when the measurement is running, click on a value and enter a new value to change it in the MicroAutoBox II.

Click on the lightning symbol named *Start the measurement* or any of the adjacent symbols to start, pause or stop the measurements. For a few additional basic features in CANape read [10].

A.6 XCP on Ethernet

XCP on Ethernet uses the same connection as used when downloading a model from Simulink to the MicroAutoBox II. This means that the same connection as explained in Section A.2 needs to be established. The only difference from the previous connections is that the CANcaseXL log does not need to be connected to the MicroAutoBox II. In the case of this guide though, the CANcaseXL log still needed to be connected to the computer since it held the license for CANape.

Before setting up XCP on Ethernet XCP on CAN should be set up according to the previous descriptions of this guide. Then, the following changes can be made:

1. Enter *rti* in the Matlab command window and go to **Blocksets** ⇒ **RTI ETH XCP Blockset** to gain access to the XCP on Ethernet blocks seen in Figure A.8.

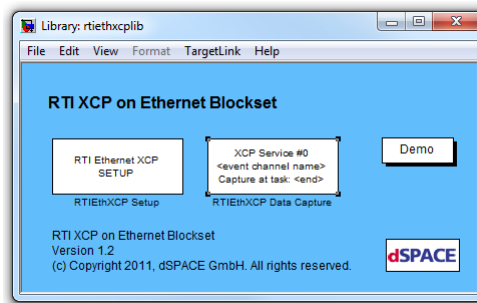


Figure A.8: Blocks for utilizing RTI on Ethernet. This window can also be accessed by entering *rtiethxcp* in the Matlab command window.

2. Add the blocks *RTIEthXCP Setup* and *RTIEthXCP Data Capture* to the Simulink model.
3. In the *RTIEthXCP Setup* block, change *Use XCP via* to *Ethernet Host Interface*.
4. In the same block, change and/or take note of the port number displayed in the *Ethernet port* field.
5. In the CAN CONTROLLER SETUP block, go to the **XCP**-tab and disable **Enable XCP support**.

6. Delete the *RTICANXCP data capture* block in the Simulink model.
7. Go to **Tools** ⇒ **Real-Time workshop** ⇒ **Options...** ⇒ **Real-Time Workshop** in the Simulink model.
8. In the **TLC options** field, change *-aGenerateASAP2=0* to *-aGenerateASAP2=1*.
9. Download the model to the MicroAUtoBox II. If an error during the building occurs, read Section A.7 comment 2.
10. Open CANape and go to **Device** ⇒ **New from database...**
11. **Open** the .a2l file created when building the Simulink model by selecting it in the *Select database for the device*-window.
12. Select **Offline**.
13. Go to **Device** ⇒ **Device Configuration**.
14. Click on the **+** next to *Protocol* under the newly created device and select **Transport Layer**.
15. Change **Host** to *192.168.140.1* (the default IP address for MicroAutoBox II) and **Port** to the port number chosen in step 4.
16. Right-click on the device name and select **Online**. It might have to be taken offline and then back online again to get the *Cache Synchronization*-window.
17. Select **Upload** and click on **OK**.
18. If there are other devices in the device list, deactivate the ones not used by right-clicking on them and deselect **Device active**.

XCP on Ethernet is now ready to be used in the same way as XCP on CAN was used.

A.7 Comments

1. As mentioned before the installation of Real-Time Workshop and TargetLink caused a lot of trouble. Therefore the following comments explain, in short, how these problems were solved.
 - Even if running on a 64-bit operating system, a 32-bit Matlab were installed. This was needed since all the programs weren't 64-bit compatible.
 - Windows *Compatibility mode* where deselected according to [11].

- Real-Time Workshop (also known as RCP and HIL 7.1) and TargetLink were installed with two different CDs. To install them in the same directory, which is required, TargetLink 3.1 was installed first. Then, to install Real-Time Workshop, the *Install_RCP_HIL.exe* file found in the RCP&HIL folder on the other CD was executed. *It does not work to run dSPACE Master Setup instead.*
2. The *-aGenerateASAP2=1* command in Real-Time Workshop option changes when *Enable XCP support* is changed in the CAN CONTROLLER SETUP block. When *Enable XCP support* is enabled *-aGenerateASAP2=1* and when it is disabled *-aGenerateASAP2=0*. There is a bug in Real-Time Workshop 6.7 which was used in this report. The bug occurs when building a model where *Enable XCP support* is disabled and *-aGenerateASAP2=1*, which is required when using XCP on Ethernet. If an error implying this occurs when building the model (an error saying there is something wrong with a file not related to the model) close Matlab and run the following hotfix file from dSPACE:
http://www.dspace.de/hotfixes/DS_RTI_67_HF218732.exe.
 3. When, for example, sending a message with a two byte (or larger) signal from CANalyzer to the model on MicroAutoBox II, or when reading a signal on the CAN in CANalyzer, the bytes will appear as if they have switched places⁶. The signal 07E8 will for example appear as E807. This should be remembered when using CANalyzer since CANalyzer is connected directly to the CAN. When sending from one application to another through the CAN this will not be a problem though.

⁶This due to the two different orders to represent bytes, big-endian and little-endian.

Appendix B

Simulink models with appertaining values and enlarged figures

B.1 Simulink

This section contains most of the Simulink models used. The values used during Simulations are added in the captions of the figures.

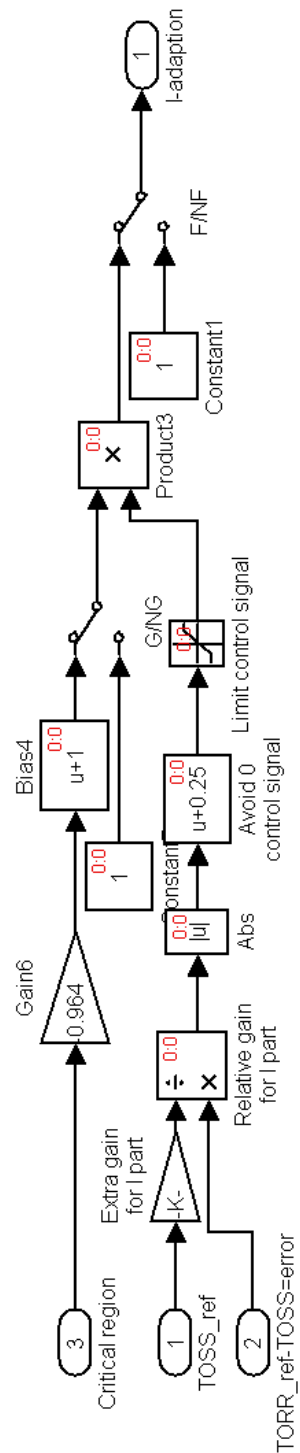


Figure B.1: Enlargement of Figure 5.1. Gain 6: 95%-99.9% control signal cut away if critical region active. Extra gain for I part: When I adaption is active a large I-gain may be used, value= 0.25 equals 4 times stronger. Avoid 0 control signal: Is used to avoid a lock when the control signal is completely canceled when change is needed.

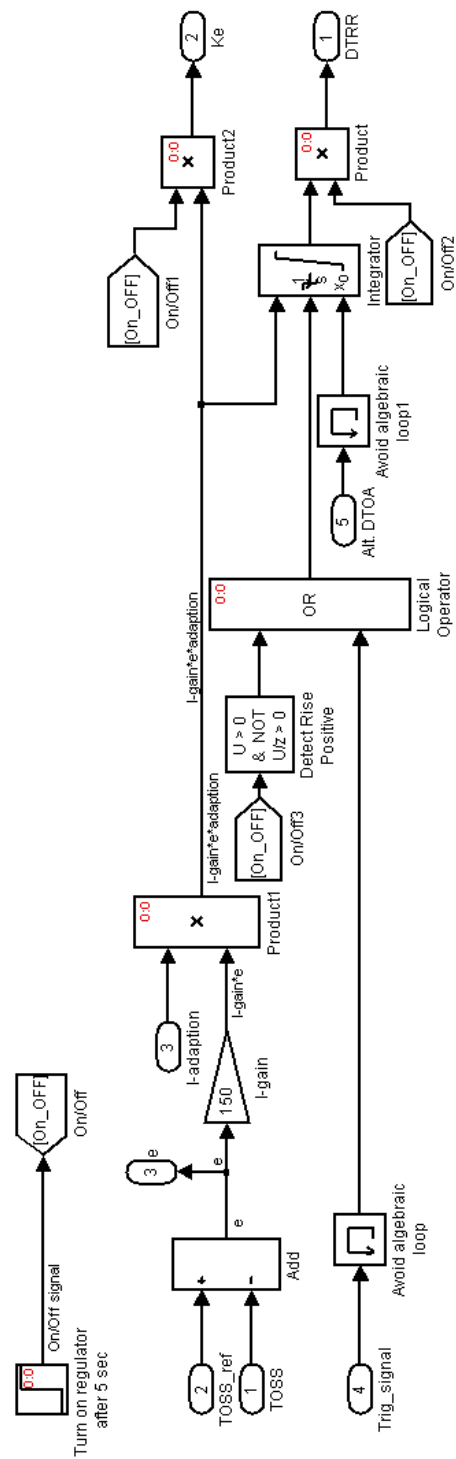


Figure B.2: Enlargement of Figure 5.2. I-gain: Value=150. ON_OFF: Is a precaution to prevent the controller to start trying to control before the system is ready. The factor I-adaption increases or decreases the control signal depending on the situation.

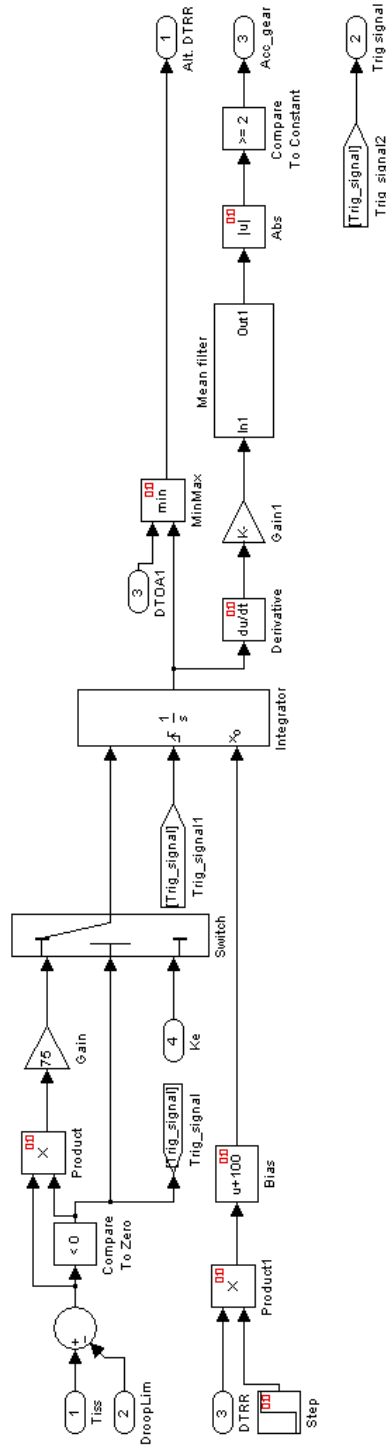


Figure B.3: Enlargement of Figure 5.3. Bias: The bias 100 is added so that the droop limit controller stays a little bit over the velocity controller during normal operation. The gain1 is 1/1000 to get the derivative signal more easily handled. The mean filter output is the mean of the last 10 values.

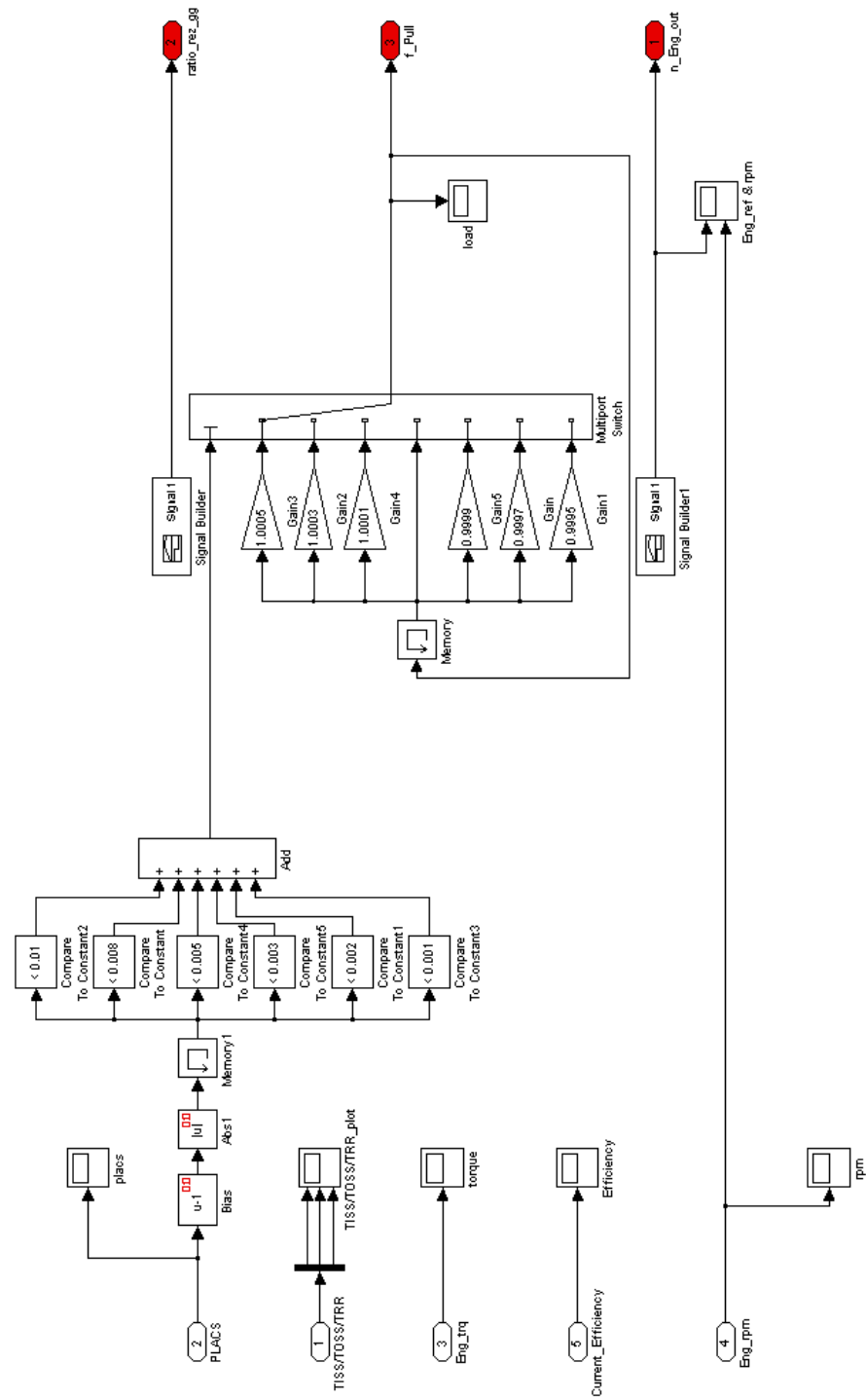


Figure B.4: Enlargement of Figure 3.3. For the values of Gain-Gain5 as well as the compare to constant, see Table 3.1.

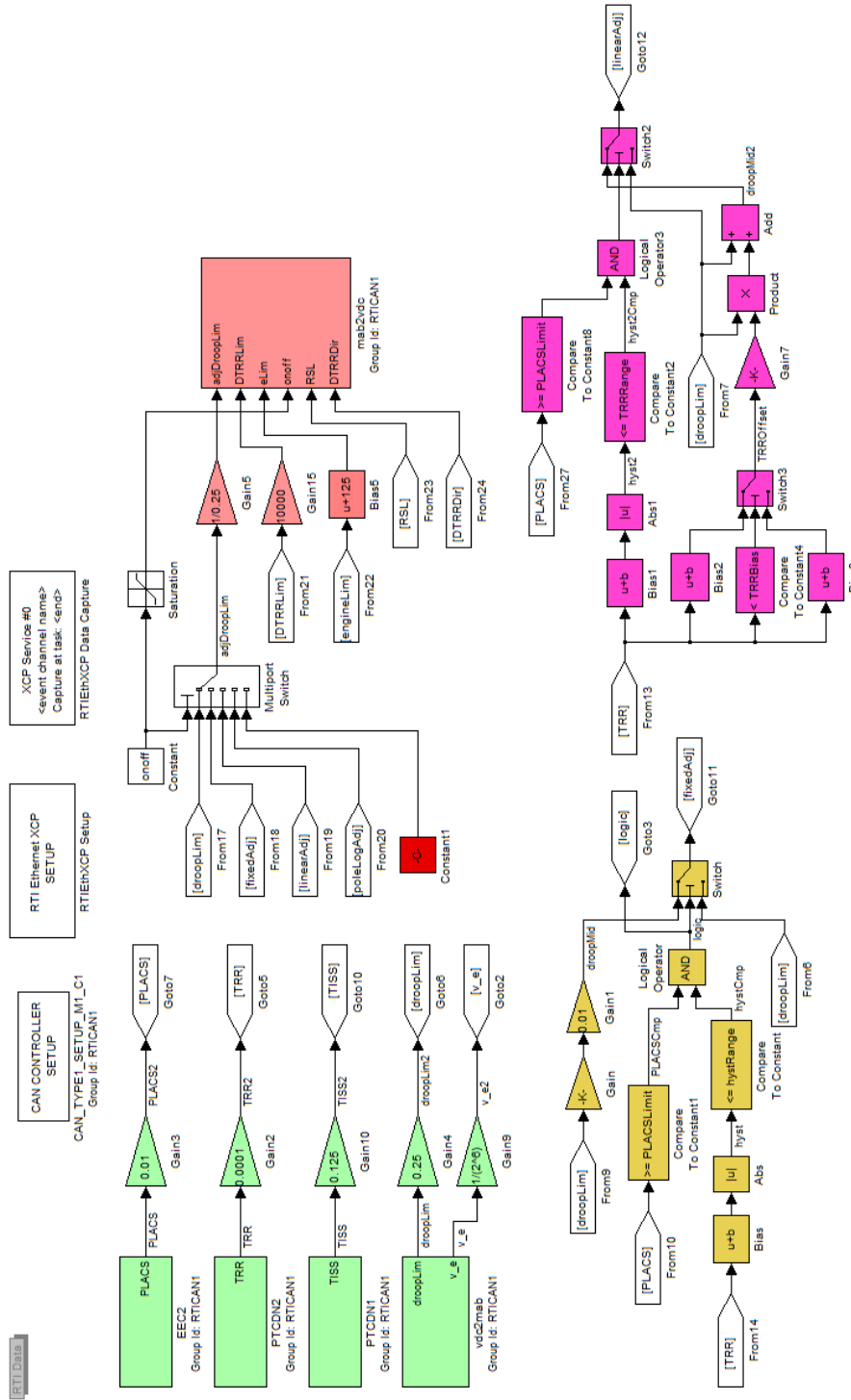


Figure B.5: Enlargement of the overview of the MAB program part 1.

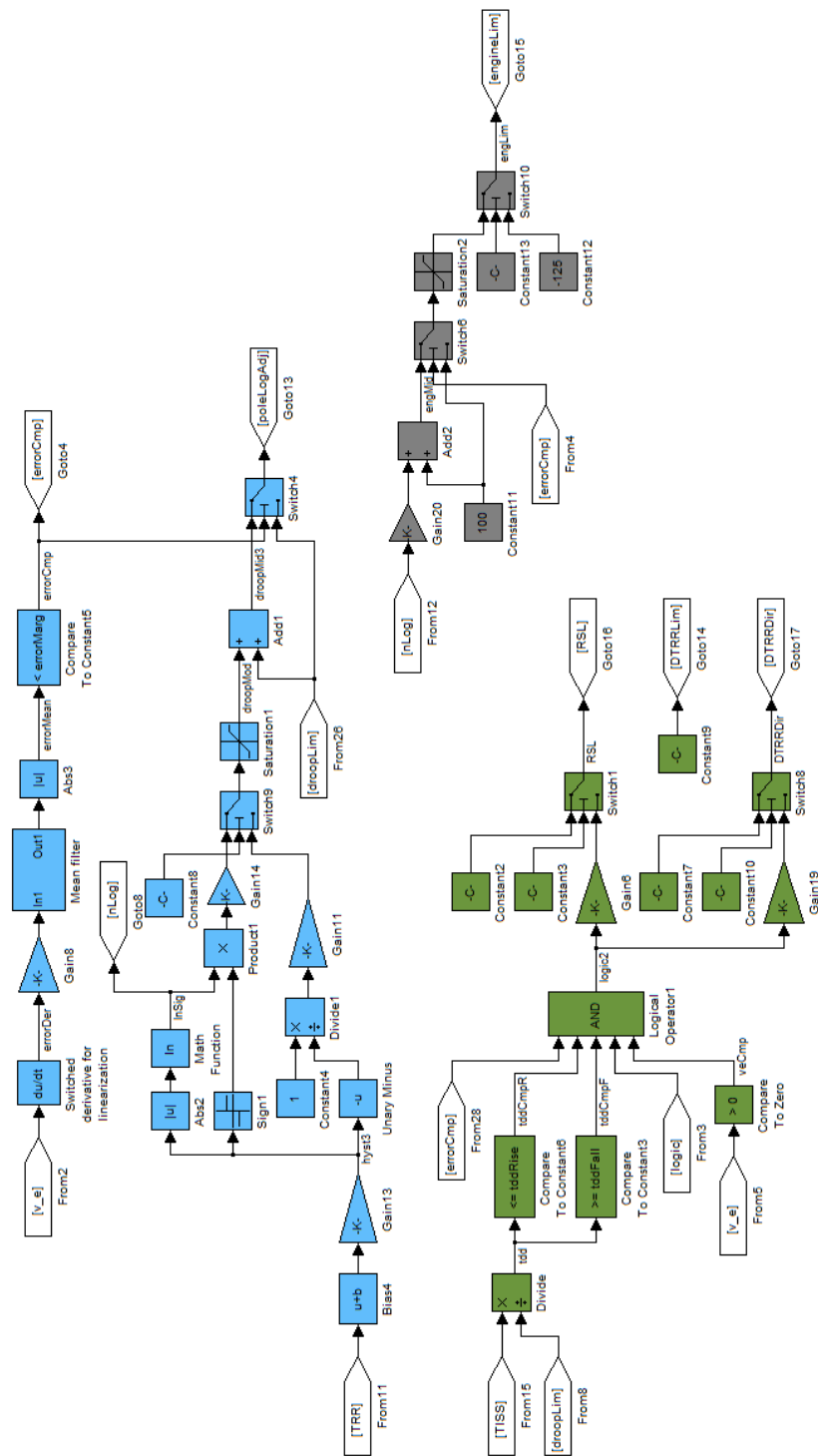


Figure B.6: Enlargement of the overview of the MAB program part 2.

B.2 Large figures

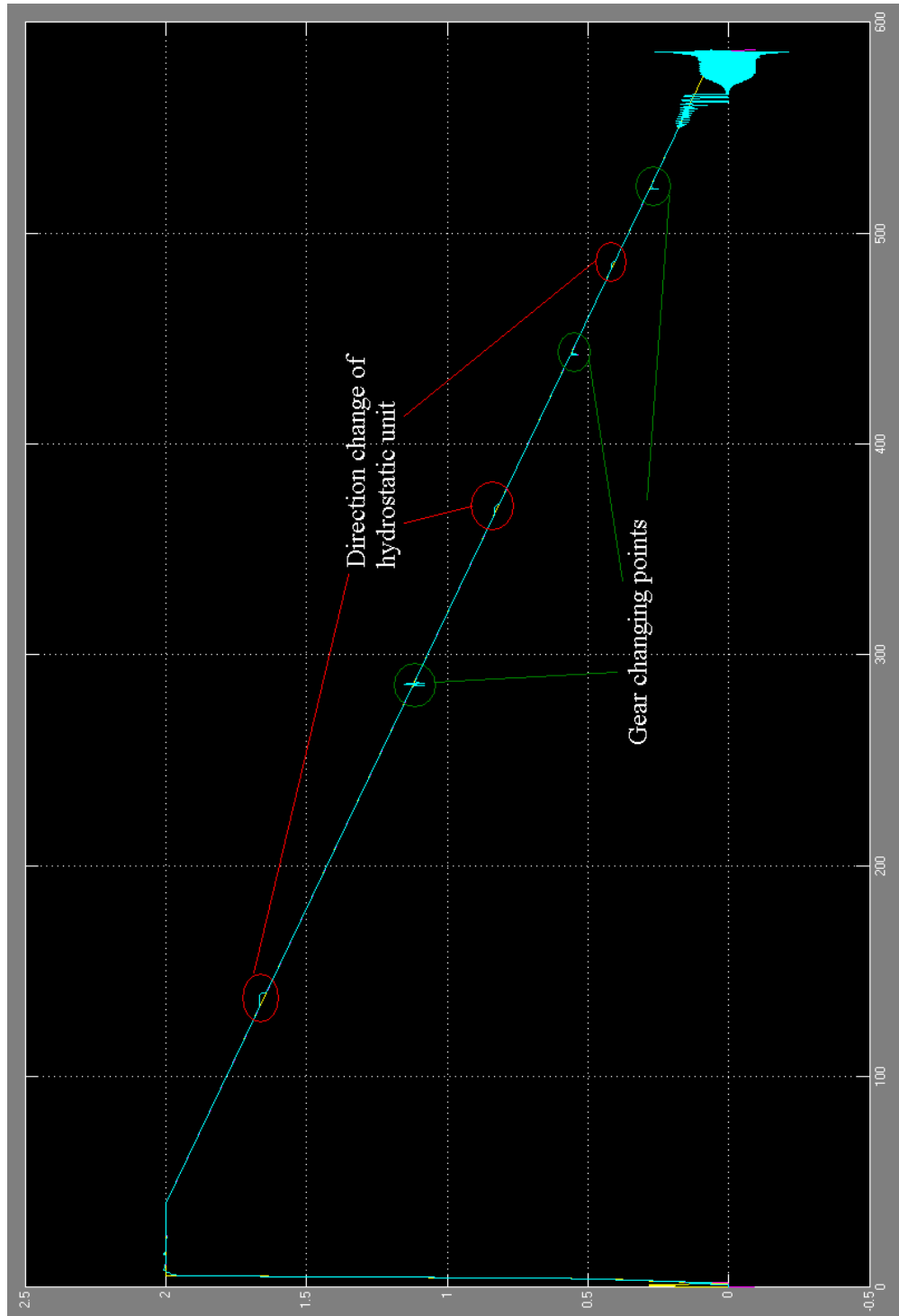


Figure B.7: Enlargement of Figure 3.6.

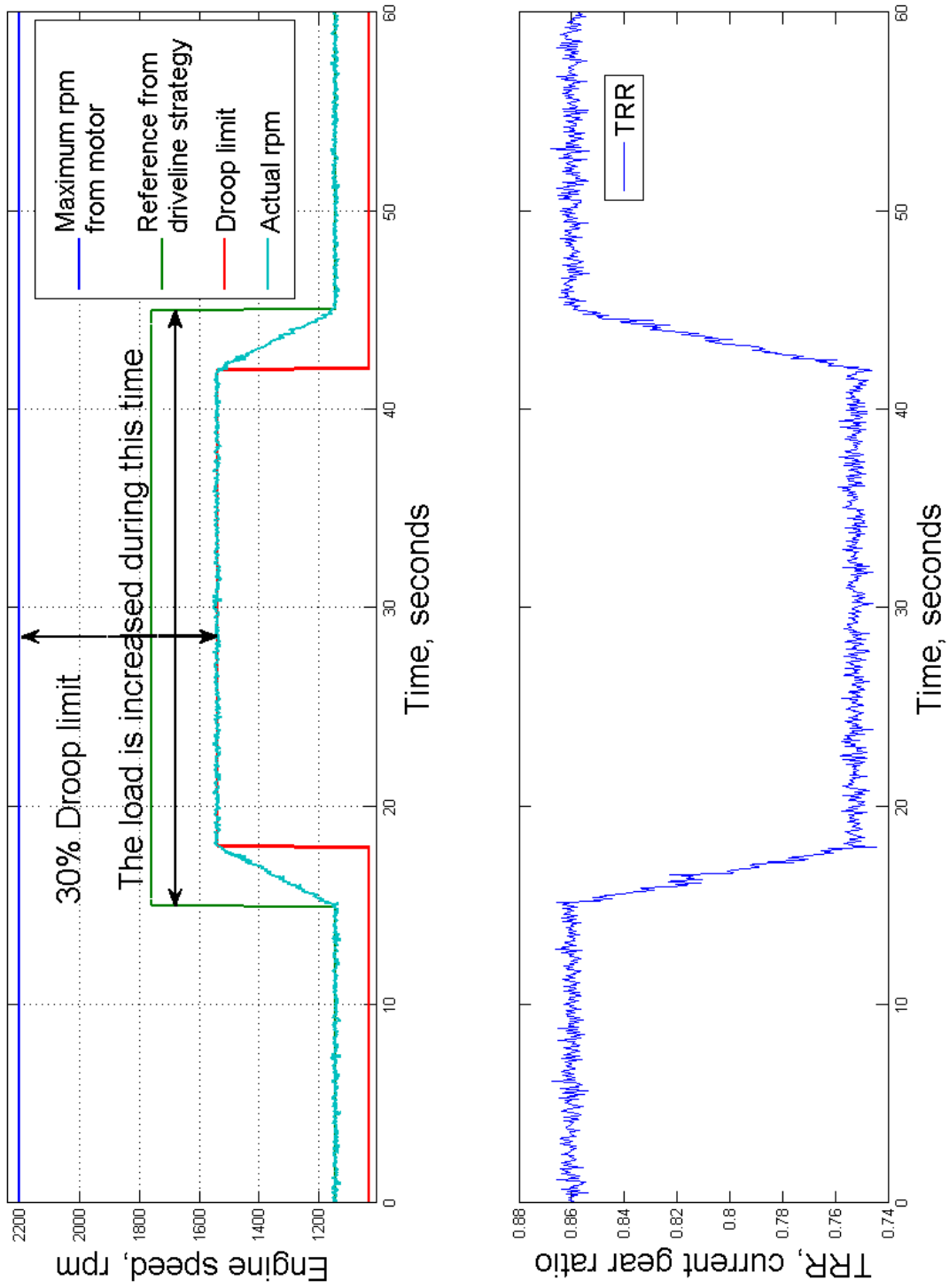


Figure B.8: Enlargement of Figure 2.12.

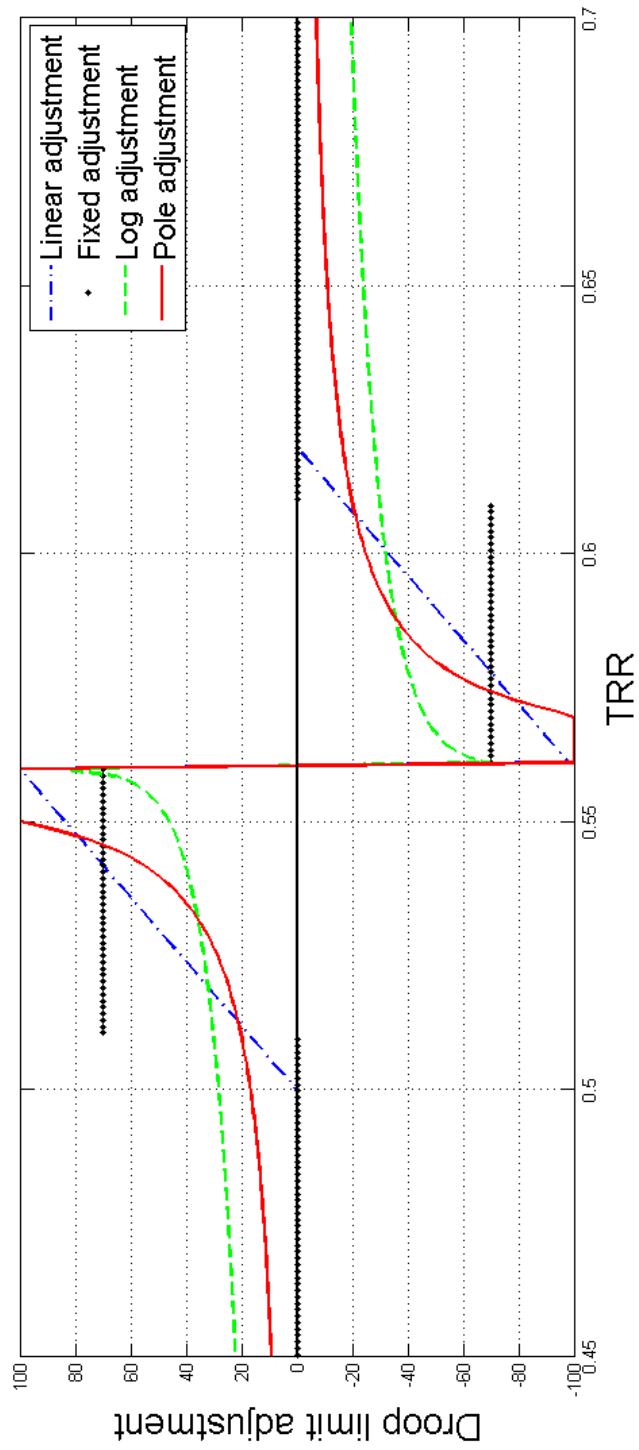


Figure B.9: The different alternation made to the droop limit by the different approaches.

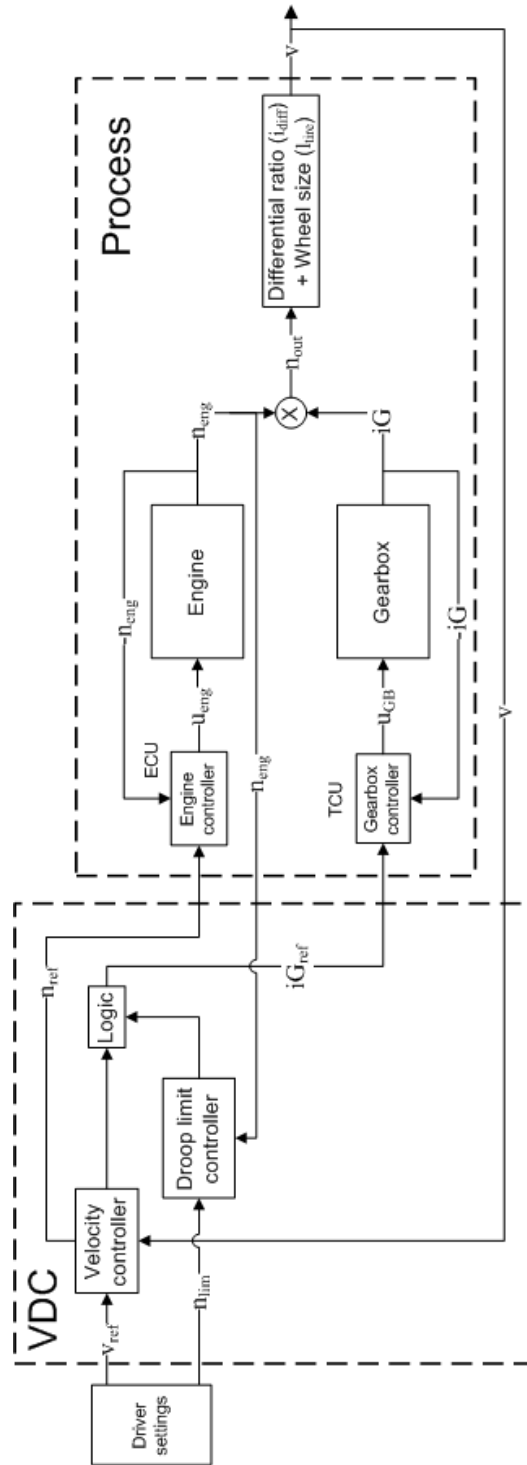


Figure B.10: Overview of the controlled process, logic represent different approaches to solve the gear alternation.

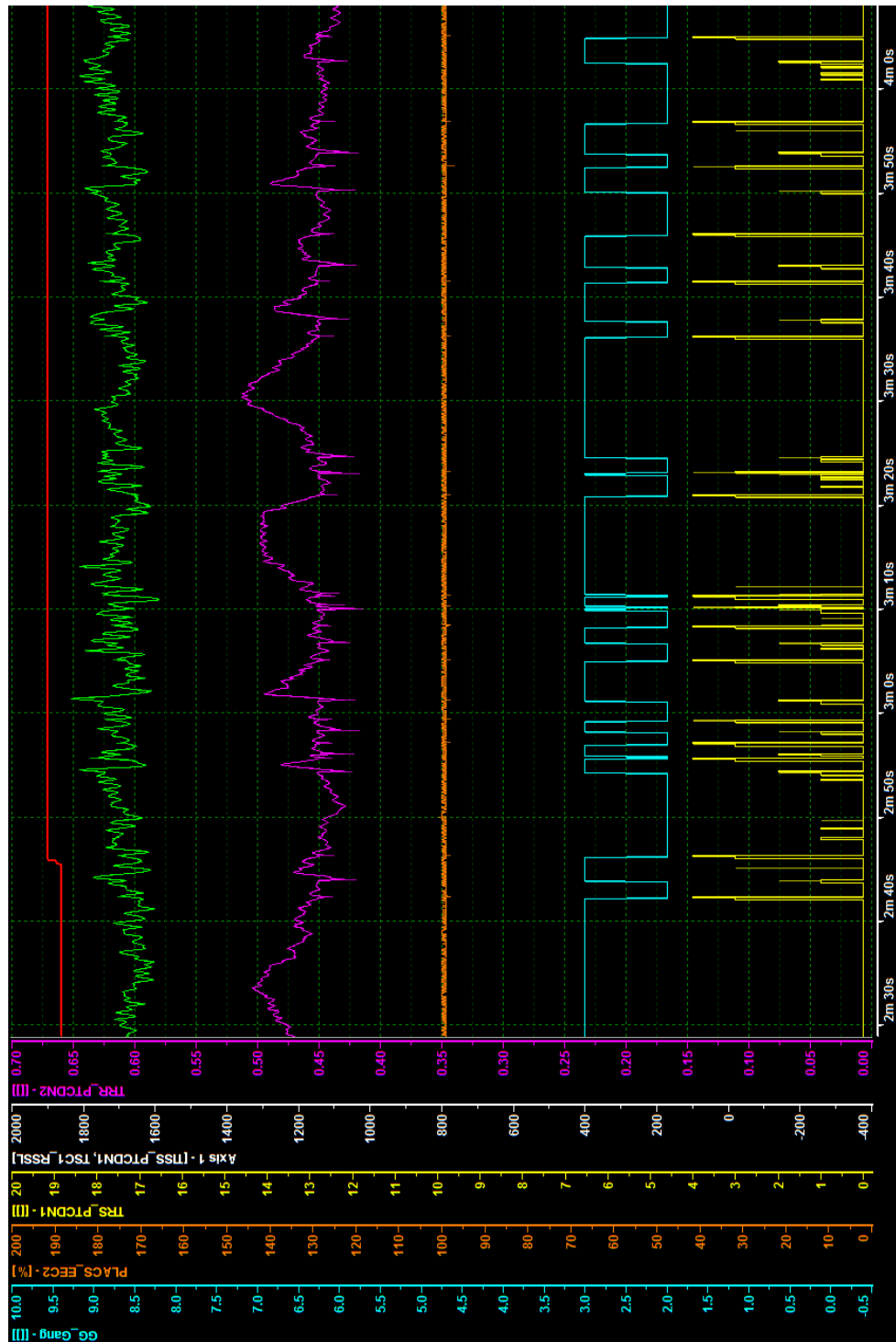


Figure B.11: Gear alternations while driving on the field.

Appendix C

Logbook from test runs on Xerion 5000

12/12-12

Software test on the real machine, first try. Connection of MicroAutoBox II and accessories were successful. The data was easy to obtain while connected but unfortunately the USB-network adapter kept disconnecting from the computer which interfered with the logging of data. This has also been a problem before at the office and no good reason for this behavior has been found. Most of the time when this occurs the LEDs on the adaptor stops flashing and a message appears saying the computer can't recognize the USB device, but sometimes that is not the case. Then the only way to notice the error is to pay attention to the loggings and see when data is lost. Alteration of the program is very hard to implement in the field due to the movement of the machinery and the cold environment. During the test the gear switching point was found, it occurred at $TRR = 0.37$. Drives with the droop limit adjustment was tried, it did reduce the gear alternation but didn't remove them completely. Further adjustments of the trigger signals are needed. The parameters are harder to adjust on the real tractor though due to the fact that gear alternation is much easier obtained and kept occurring constantly in the simulations. Observation of the RTS signal showed intentions of gear shifting but not all got through to full gear shifts. To lower the droop limit seemed to be more effective than the increased droop limit. This effect is a bit odd and contradicts the results from the simulations that indicated that a higher droop limit would have a more desired effect. This result needs to be further evaluated and confirmed during the next run. Plans for next test run:

- Improve user interface to highlight important signals, hopefully easier tuning is obtained by this.
- Try a new USB-network adapter that's hopefully not disconnecting all the time so data from the runs may be saved and analyzed at the office.

- Get logged data from a pair of good gear alternation runs for tuning and analyzing back at the office.
- Evaluate which of the droop limit adjustments (higher or lower) that have the more desirable effect.
- Try the effect of the *RSL* signal.
- Try to tune the *RSL* controller to solve the gear alternation problem.
- Check the trigger signal that the *RSL* controller uses, if the signal behaves good other controllers can benefit to use this signal as well.
- Check several conditions for the gear alternation to have the opportunity for alternative trig signals.

18/12-12

The setup worked fine, though it should be kept in mind that the right VDC needs to be connected to the system if all signals are to be used correctly. Apparently the *RSL*, range shift limitation, is not implemented on the tractor or the value for *RSL* that we send does not reach its destination. This has created a bit of a fuss at the department because the gearbox is sold with this feature even though it might not even be implemented in the real vehicle. Because of this error the *RSL* controller could not be tested and evaluated. The linear droop limit controller has a much more desirable rpm signal which follows the droop limit better than the fixed droop limit controller. The alternation of the droop limit is smaller with the linear controller and therefore the effect of this change is harder to detect for the driver, which is a good review. It was also noticed that decreasing the droop limit where better in some situations and increasing it where better in others. No explanation of when to increase or decrease the droop limit has yet been found. For future notice the load should be in position 5 on the tractor to obtain a good load that keeps *PLACS* at 1 while it is possible to switch between the gears. The new USB-adaptor was a great improvement and didn't crash once during the test drive. Gear alternation was obtained by alternation of the cruise control, which is highly unlikely to obtain the same result as heavy load and droop limit alteration. To do before the next test run:

- Talk to the department and get the *RSL* working.
- Check the load estimations to see if it can be used to determine the choice of increased or decreased droop limit adjustment.
- Further research regarding the alternative way to create gear alternation.
- (Added after simulations in the lab) Test if the result that determination between increasing/decreasing droop limit depends on the current load.

1/2-13

The signal *RSL* is set to one and two, this makes no difference and the vehicle gears as usual. The pole droop adjustment gives us hope and successfully suppress the gear alternation. Though it should be kept in mind that on the test track the alternation only occurs about once every 10 second cycle but in the field the alternation occurs up to once per second. But the results are still positive and further testing is needed to confirm the results. If the alternation occurs more frequently the *RSL* no prediction signal should be applied to avoid gear switching by mistake. Other observations were that a fixed alteration of the droop limit fixes the problem for the current load but instead another load is badly combined with the new droop limit. The load options on the test track is a bit limited and droop limits can be chosen so that no alternation occurs, but this is most likely due to the fact that the right load is not acquired. On the track the TOSS/TISS was more or less the same as *TRR* unlike on the tractor simulator. To do before the next run:

- Hope that someone fixes the *RSL* implementation until next test drive.
- Implement and test the logarithm adjustment of the droop limit. This is because the pole adjustment gives good hope and the log approach is quite similar, but have the advantage of not increasing as steeply.
- Look over the possible opportunities to test drive at some field to see the controllers effect in the real soil, with full gear alternation and dynamic load.

20/2-13

The new implementation of the *RSL* signal in the VDC works well. The trigger conditions worked well and the gear alternation was suppressed in a good way. The trigger conditions were not tuned during this run so the solution has got a large room for improvement. It was noticed that the engine speed alternates in the critical region, this effect occurred with and without any influence from the MAB. A good set of data was collected for the *RSL* run however during the test of the pole adjustment the breaking wagon started to behave in an undesirable way and no further testing of the pole adjustment was performed. An interesting observation was made that the PLACS dropped before the range shifting each time this effect can be seen in figure 7.10. This effect was believed to occur when the reference signal (*RSSL*) was change. This effect was also believed to be the explanation to why the motor speed alternates.

- Try to get another test drive to test the pole adjustment.
- Try booking a test drive in the field.

Appendix D

CAN message table

D.1 Created CAN messages

	byte							Identifier	
	0	1	2	3	4	5	6	7	
mab2vdc	adjDroopLim		DTRRLim		eLim	*	<i>not used</i>		18E705F9
vdc2mab	droopLim		V_e		<i>not used</i>				18E7F905

Table D.1: Created CAN messages

	bit							
	0	1	2	3	4	5	6	7
* Byte 5	onoff		RSL		DTRRLimDir		<i>not used</i>	

Table D.2: Byte 5 of mab2vdc

D.2 Used CAN messages

	byte							Identifier	
	0	1	2	3	4	5	6	7	
EEC2	<i>not used</i>		PLACS		<i>not used</i>				CF00300
PTCDN1	<i>not used</i>				TISS		<i>not used</i>		CF06703
PTCDN2	<i>not used</i>		TRR		<i>not used</i>				CF06803

Table D.3: Used CAN messages

D.3 Description of the signals in the CAN messages

adjDroopLim is the adjusted droop limit that is sent to the VDC from the MAB when one of the droop limit approaches are activated.

droopLim is the droop limit set by the driver.

DTRRLim is the value that the gearbox should be locked above or below depending on the value of **TRRLimDir**.

DTRRLimDir determines if the gearbox should be locked above or below the gear shifting point. 0 equals no limitations, 1 equals a lock below and 2 equals a lock above value set by **DTRRLim**.

eLim is the engine limitation. This value corresponds to how many percent of the engine torque that should be available.

onoff is a onoff switch that tells the VDC if a droop limit adjustment should be active or not.

PLACS is a signal from the engine that states how much of the engine torque that is currently used.

RSL is the range shift limitation signal. It states whether the gearbox should allow shifting or disapprove shifting. 0 means that no limitation are active, 1 means no up shift, 2 means no down shift and 3 means look ahead which means no prediction.

TISS is the input speed to the gearbox.

TRR is the gearbox current gear ratio.

V_e is the velocity error of the vehicle.

D.4 Table of the signals used in the CAN messages

	Message	Identifier	Startbit	Length	Scale	Offset
adjDroopLim	mab2vdc	18E705F9	0	16	2^2	0
droopLim	vdc2mab	18E7F905	0	16	2^2	0
DTRRLim	mab2vdc	18E705F9	16	16	10000	0
DTRRLimDir	mab2vdc	18E705F9	44	2	1	0
eLim	mab2vdc	18E705F9	32	8	1	125
onoff	mab2vdc	18E705F9	40	1	1	0
PLACS	EEC2	CF00300	16	8	100	0
RSL	mab2vdc	18E705F9	41	3	1	0
TISS	PTCDN1	CFF6703	32	16	2^3	0
TRR	PTCDN2	CFF6803	16	16	10000	0
V_e	vdc2mab	18E7F905	16	16	2^6	0

Table D.4: Used signals on CAN messages

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<i>Abstract</i> The subject of this thesis was to investigate the possibility of a supplemental control algorithm to suppress gear alternation in the ZF ECCOM gearbox series. The acquired solutions were implemented on a dSpace MicroAutoBox II and connected to a Claas Xerion 5000 to evaluate their effect. The different approaches have gone through three steps of validation, first a Simulink model simulation, secondly a tractor simulator test, and finally tests on the real tractor.			
<i>Keywords</i> dSpace MicroAutoBox II, ECCOM gearbox, CVT, continuously variable transmission, gear hunting, gear alternation, range shifting, CANape, CANalyzer, droop limit, ZF Friedrichshafen AG, driveline, powertrain, VDC, ECU, TCU, vehicle CAN-buses, Simulink.			
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