ENGINE COMPUTER MANUAL

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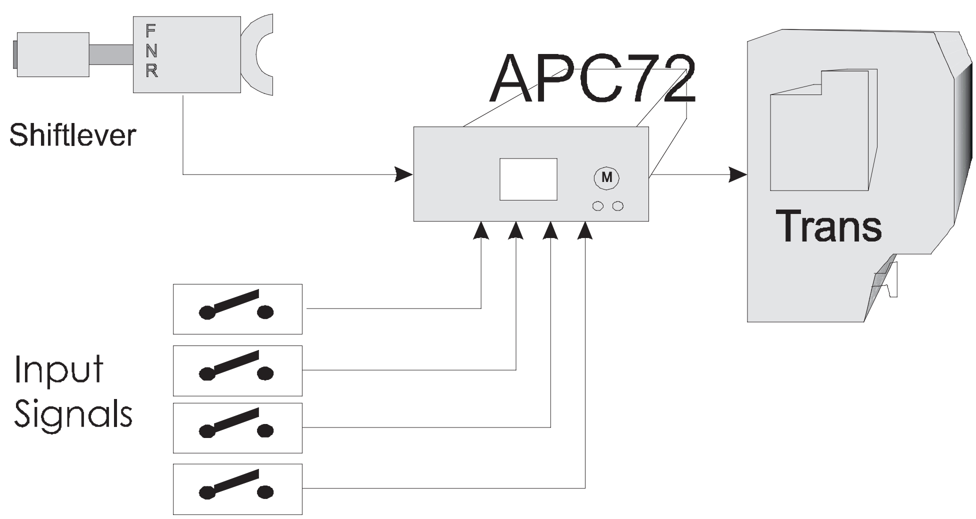
Generic Transmission Controller APC72

1. Functional specification

1.1 General

The APC72 is a device used to control the shifting of many Spicer Off-Highway Powershift transmissions. While being easy to operate, it takes care of all transmission related functions in order to achieve superior shift quality and high reliability.

The built in self-test and trouble shooting features allow fast problem resolution.
The integration in the vehicle wiring system is straightforward and mainly involves connections between the shift selector, the APC72 and the transmission control valve.



Additionally the APC72 requires some connections for supplying power and for selection of different operating modes. Refer to section 5.2 for details about the installation.

1.2 External interfaces

The APC72 is connected to the vehicle wiring system using a 30 pole Packard Electric Metripack Connector. The mating connector has following components and Packard part numbers:

Part	Packard Part number
Receptacle	12048455
Contact	12089290 (0.35-0.5 mm²)
	12103881 (0.8 - 1.0 mm²)

The different connector pin functions for the APC72 are listed below.

Following type designations are considered:

Ptg	pull to ground	**input** internally pulled high, must be connected to Ground to activate
Ptp	pull to plus	**input** internally pulled low, must be connected to Plus to activate
Stg	switch to ground	**Output** switches internally to Ground. Other side of Load must be connected with Plus
Stp	switch to plus	**Output** switches internally to Battery plus. Other side of Load must be connected with Ground

Below table all references to terminals have prefix **TC** meaning they refer to the APC72 connector pins.

APC72 CONNECTIONS

Wire	Pin	Function	Type	Comment
TC01	A1	Battery + 12V/24V		Connect to Battery through 6 A fuse
TC02	B1	Ground		Connect to chassis Ground
TC03	C1	PWM0	stg	Warning lamp
TC04	D1	Solenoid 1	stp	Gear position selection solenoid (1)
TC05	E1	Solenoid 2	stp	Gear position selection solenoid (2)
TC06	F1	Forward Solenoid	stp	Forward / Neutral selection solenoid
TC07	G1	Reverse Solenoid	stp	Reverse / Neutral selection solenoid
TC08	H1	PWM1	stg	Lockup solenoid
TC09	J1	Splitter Solenoid	stp	Gear position selection solenoid (splitter)
TC10	K1	PWM solenoid supply	stp	PWM solenoid supply
TC11	A2	Battery + 12V		Connect to Bat+ : **for 12 V applications only**
TC12	B2	Signal Ground		For speed sensors only
TC13	C2	Input 0	ptp	Shift lever Forward input
TC14	D2	Input 1	ptp	Shift lever Reverse input
TC15	E2	Input 3	ptp	Shift lever range selection
TC16	F2	RXD (RS232)		Not used
TC17	G2	CAN H		Not used
TC18	H2	Input 4	ptp	Shift lever range selection
TC19	J2	Input 6	ptp	Not idle / Idle input
TC20	K2	Analogue input 1	ptg	Not used
TC21	A3	Engine speed		Engine speed - inductive pickup
TC22	B3	Input 7		Lockup Enabled / Disabled
TC23	C3	Turbine speed		Turbine speed – inductive pickup
TC24	D3	Not used		Not used
TC25	E3	Input 2	ptp	Shift lever range selection
TC26	F3	Output8	stp	Not used
TC27	G3	TXD (RS232)		Not used
TC28	H3	CAN L		Not used
TC29	J3	Input 5	ptp	Manual/automatic switch
TC30	K3	Analogue input 0	ptg	Declutch Request Inactive (2000 ohm)/ Active (1000 ohm)

1.3 Man Machine interface

1.3.1 Shift lever

The main interface with the driver is the shift lever. It allows selecting the driving direction and the different ranges. The shift lever output signals serve as inputs for the APC72.

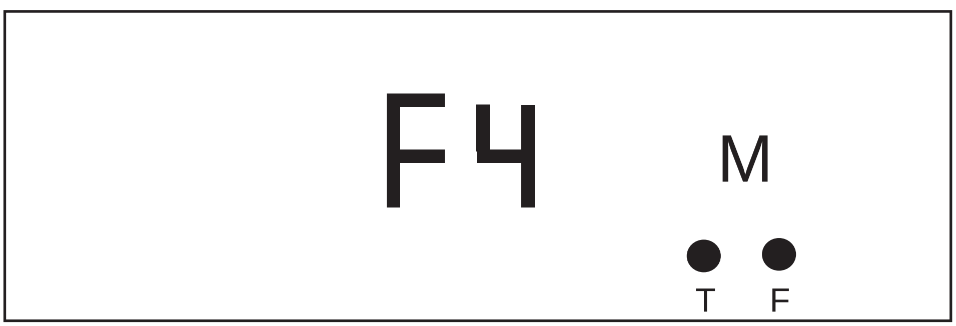
1.3.2 Display

The display is located on the APC72 front panel and consists of:

- 2 red 7-segment LED digits
- 2 status LED lamps
- a push button labeled 'M' for display mode selection.

The LED lamp labeled 'T' is yellow and is used to indicate test modes and faults.

The LED lamp labeled 'F' is red and is switched on when the APC72 is in the reset condition (see also section 2.4.2).



APC72 front panel display

Refer to Dana drawing **I/APC72A** for installation dimensions.

After power up, the display defaults to the **gear position mode**. In this mode, the left digit shows the actually engaged direction and the right digit shows the currently engaged range (gear).

Pressing the 'M' switch changes the displayed information.

While pushing the switch (and about 1 second after it is released) the display shows which information is about to be displayed.

Four modes listed in below table are available:

While pressed	Info shown	Comment
GP	n 1	This mode shows actually engaged direction and range. If either or both differ from the shift lever, the corresponding dot blinks. The example shows Neutral 1st.
SP	4.2	This mode shows vehicle speed in km/h. For speeds below 10km/h, speed is shown with 0.1km/h resolution. The example shows 4.2km/h
rS	4.2	This mode shows vehicle speed in mph. For speeds below 10mph, speed is shown with 0.1mph resolution. The example shows 4.2mph
SL	F3	This mode shows the current shift lever position. Only positions actually available on the transmission are shown. If different from the transmission, the corresponding dot blinks.

Pushing the switch activates the next mode. Pushing while in shift lever display, the gear position display is again selected.

When holding the switch for more than 2 seconds, the display shows a code identifying the severest problem currently detected, if any. The **T-led** flashes while an error is detected.

Error codes are described in section 2.4.10.

1.3.3 Other

Additionally several on/off switches with function described in section 1.6.1 are used to select different operating functions.

1.4 Operating modes

1.4.1 Normal driving

See 1.6 for detailed description

1.4.2 Self test mode

This mode is selected when the mode switch is pressed at power up.
See 5.1.2 for detailed description.

1.5 Operating Characteristics

The APC72 is designed to operate continuously under the environmental conditions described in section 3.3.

Below sections detail some specific system limits and specification data relevant for interfacing with the APC72.

1.5.1 System

Operating temperature range		-40°C to +80°C
Sealing		IP65 & IP66
Supply Voltage	Vnom Min - max.	12V 9V - 16V DC
Supply Voltage	Vnom Min - max.	24V 18V - 32V DC
Over voltage conditions		5 min @ 48V 350ms @ 226V 2 ms @ 300V
Maximum continuous total load current @ Vnom		6 Amperes

The APC72 is designed for operation at 12V and at 24V without modifications to the controller.

1.5.2 On/Off inputs

Low input level	< 0.8 V
High input level	> 2.3V
Minimum DC voltage level	- 60V
Maximum DC voltage level	+60V

1.5.3 Analogue inputs (not used)

Internal pull up resistor (to battery voltage)	11 kOhm
Input voltage range	0 to 5 V
Resolution	10 bit
Minimum DC voltage level	- 60V
Maximum DC voltage level	+60V

1.5.4 Speed sensor inputs

1.5.4.a Turbine speed

The APC72 has two input circuits for sensing turbine speed - a current loop circuit compatible with the Dana Magneto Resistive Sensor (MRS) and an **inductive** pickup input circuit. This way it's compatible with all existing sensor options on Dana transmissions.

The B.R. Lee LB22K Motor Grader uses an inductive speed sensor to measure transmission speed.

The controller only supports electrical fault detection for the MRS (short circuit or open load).

1.5.4.b Engine speed

For sensing engine speed, the APC72 accepts all existing Dana **inductive** speed pickups.

1.5.4.c Sensor circuit characteristics

Sensor type	Magneto resistive	Inductive
Electrical interface	Current sensing	Voltage sensing
Normal operating levels	7 / 14 mA	0.8 / 1.2 Vtt
Short circuit detect	yes	No
Open circuit detect	yes	no
Reverse polarity detect	seen as short ckt	N.A.
Fully protected	yes	yes

1.5.5 On/Off outputs

Maximum continuous load current	1.5 Amperes
Short circuit detect	yes
Open circuit detect	yes
Redundant shutdown path Common for 5 outputs	yes
Fully protected	yes

1.5.6 Analogue outputs

Output current	10mA - 1100mA
Resolution	8 bit
Short circuit detect	yes
Open circuit detect	yes
Redundant shutdown path Common for 2 outputs	yes
Fully protected	yes

1.6 Functional description

1.6.1 External inputs

1.6.1.a Not idle/idle switch (wire 19)

Input is active when the throttle pedal is applied. Input is inactive when the throttle pedal is released. The information received from this input is vital for correct functioning of the control unit during automatic shifting.

1.6.1.b Manual/Automatic switch (wire 29)

1.6.1.b.1 Manual →Automatic

Switching from manual to automatic is possible in all circumstances.

1.6.1.b.2 Automatic →Manual

Switching from automatic to manual is possible in all circumstances.

Note : when the shiftlever is lower than the transmission gear, the downshift protection will inhibit downshifts at too high speed (see 1.8. Downshift protection).

1.6.1.c Lockup enabled/disabled (wire 22)

Lockup can be enabled and disabled with a switch on wire 22. If wire 22 is activated, lockup is enabled. If wire 22 is not activated, lockup is disabled.

1.6.1.d Declutch Request inactive/active (wire 30)

A request for Declutch is made with a switch under the brake pedal on wire 30. The switch is normally closed and thus the analog input measures 2000 ohms. Resistance greater than 1800 ohms yields an inactive request. Conversely opening the switch by depressing the brake pedal will yield 1000 ohms and thus an active request for declutch. Declutch is only granted when the vehicle speed is below 2.3 MPH.

1.6.2 Shift lever

The main interface with the driver is the shift lever. It allows selecting the driving direction and the different ranges. The shift lever output signals serve as inputs for the APC72.

The APC72 is designed to interface with a 6 speed shift lever that generates a grey coded selection pattern as shown in below table.

Selected Position	Standard Shift lever: wire number							
	1	2	3	4	5	6	7	13
F1	BAT +			●	●	●		
F2	BAT +			●	●	●		●
F3	BAT +				●	●		
F4	BAT +				●	●		●
F5	BAT +					●		
F6	BAT +					●		●
N1								
N1	BAT +			●	●			
R1	BAT +			●	●		●	
R2	BAT +				●		●	
R3	BAT +						●	

● = Wire connected to pin 1 of standard shift lever (BAT +)

In manual mode, the transmission gear will equal the shiftlever position, provided the downshift protection is not engaged (see 1.8. Downshift Protection).
In automatic mode, there will be automatic shifting between 1st gear and the shiftlever position.

Connections to the APC72

Wire Standard shift lever	Wire on APC72
6	13
7	14
4	25
5	15
13	18

1.6.3 Overspeeding upshifts as transmission protection

In automatic mode, when the shiftlever position is higher than the transmission gear and the turbine speed exceeds the overspeeding limit of 3000 RPM, an automatic upshift will occur to protect the transmission against overspeeding.

1.6.4 Automatic shifting

1.6.4.a Automatic shifting in neutral

If the transmission is in neutral, the control unit will shift to the next higher gear when the transmission overspeeding limit is reached (3000 rpm) or will shift down when the transmission input speed after the downshift would not exceed 1800 RPM.

1.6.4.b Definitions

If lockup is engaged, the transmission is in 'lockup drive'.
If lockup is not engaged, and speed ratio is below 1, the transmission is in 'converter drive' :

$$\text{speed ratio} = \frac{\text{turbine speed}}{\text{engine speed}} < 1$$

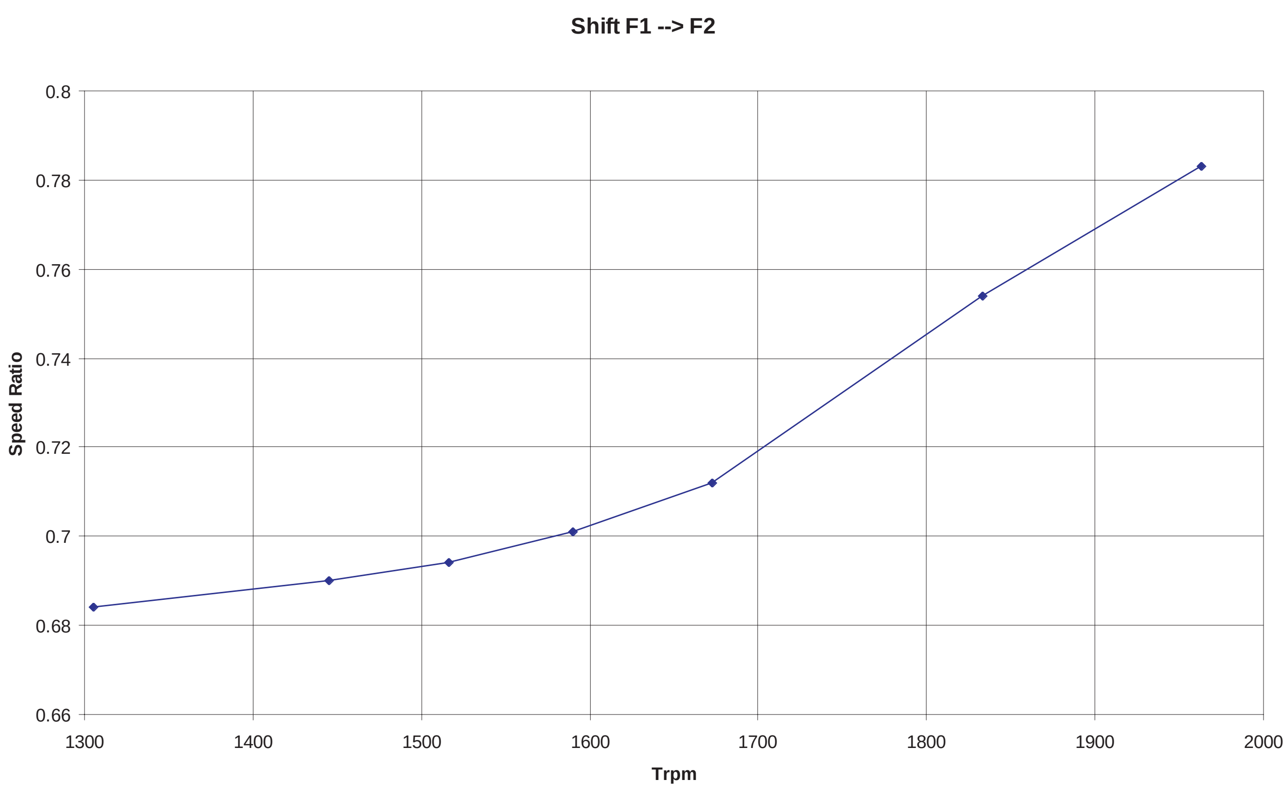
If lockup is not engaged, and speed ratio is above 1, the transmission is in 'braking mode' :

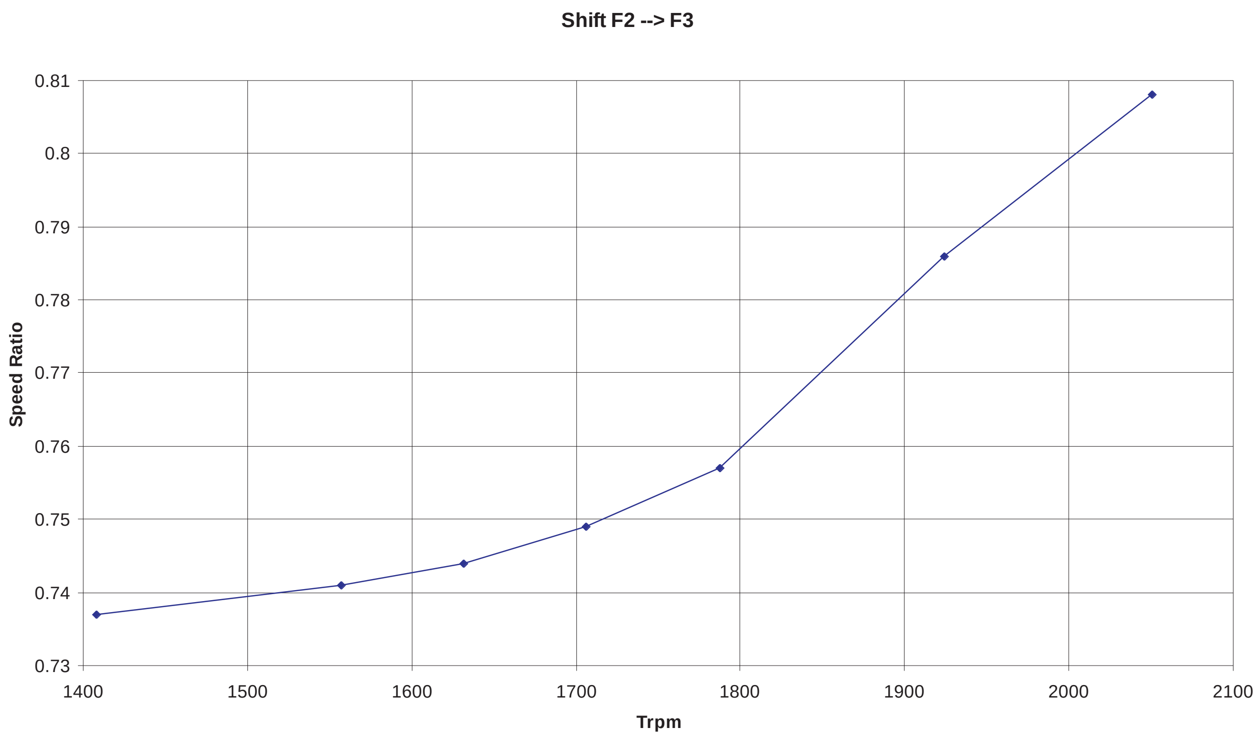
$$\text{speed ratio} = \frac{\text{turbine speed}}{\text{engine speed}} > 1$$

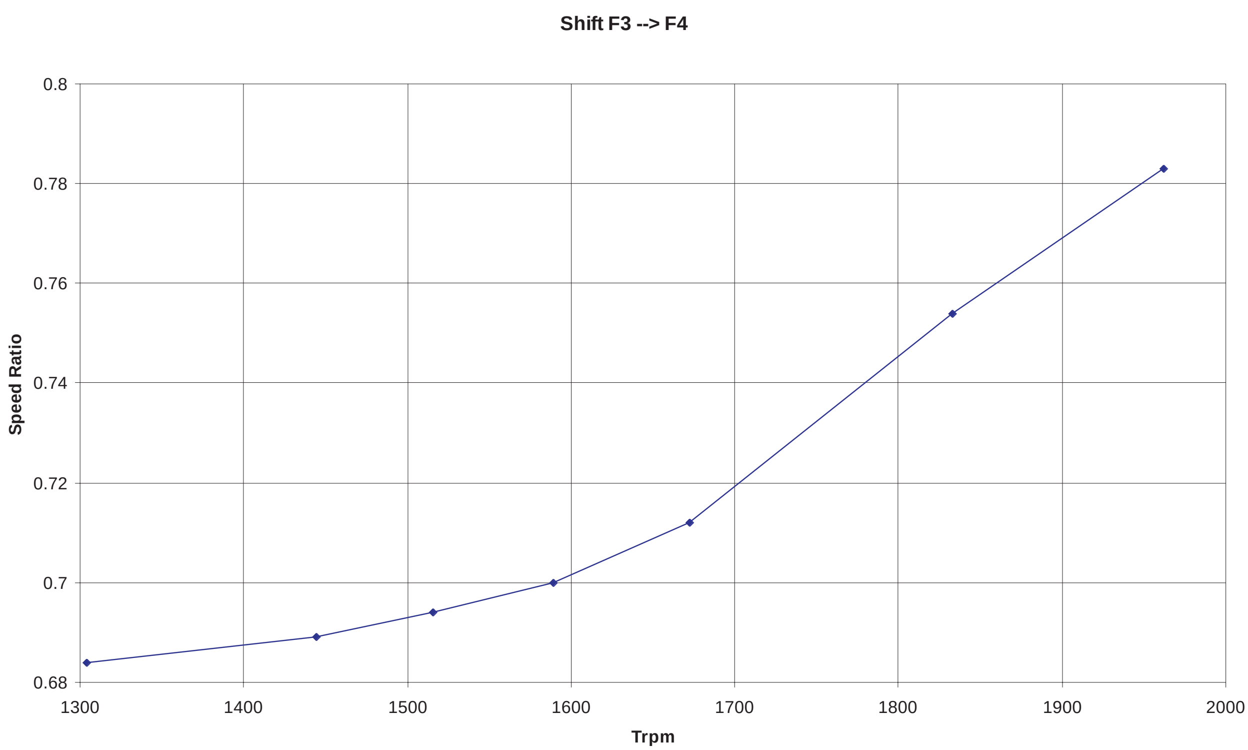
1.6.4.c Automatic shifting (if in 'converter drive')

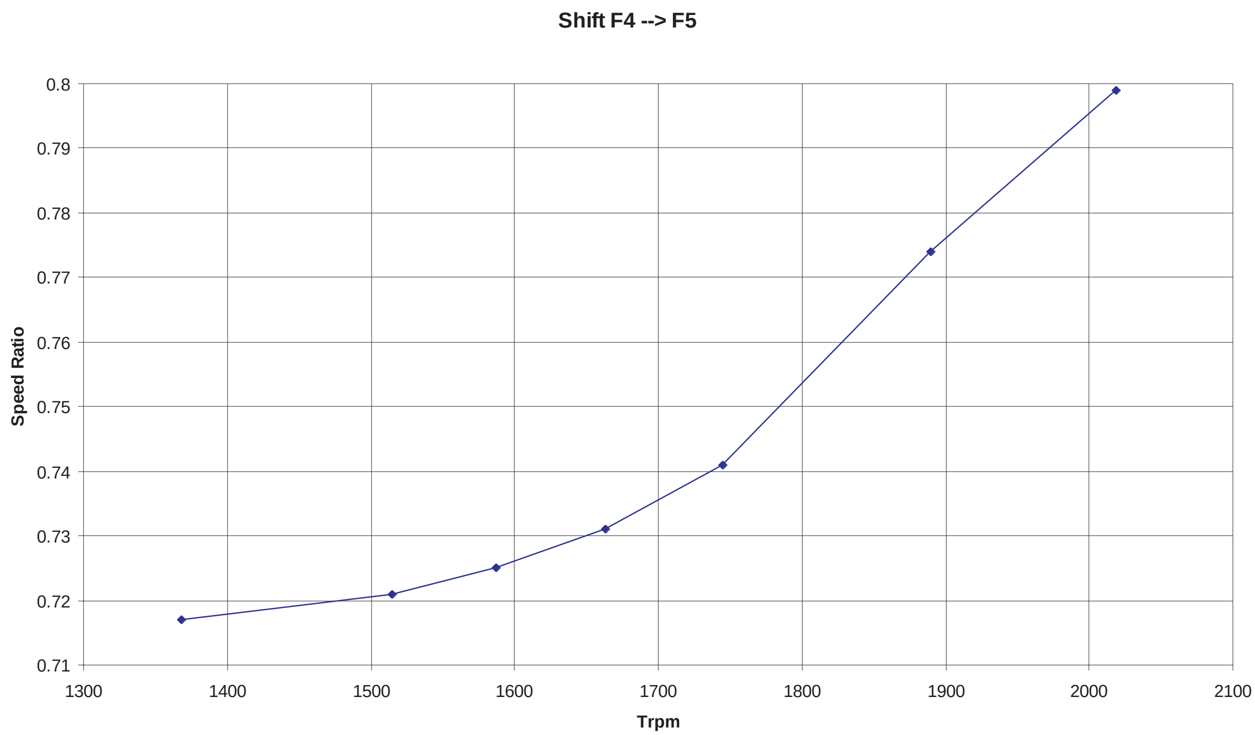
automatic upshifting

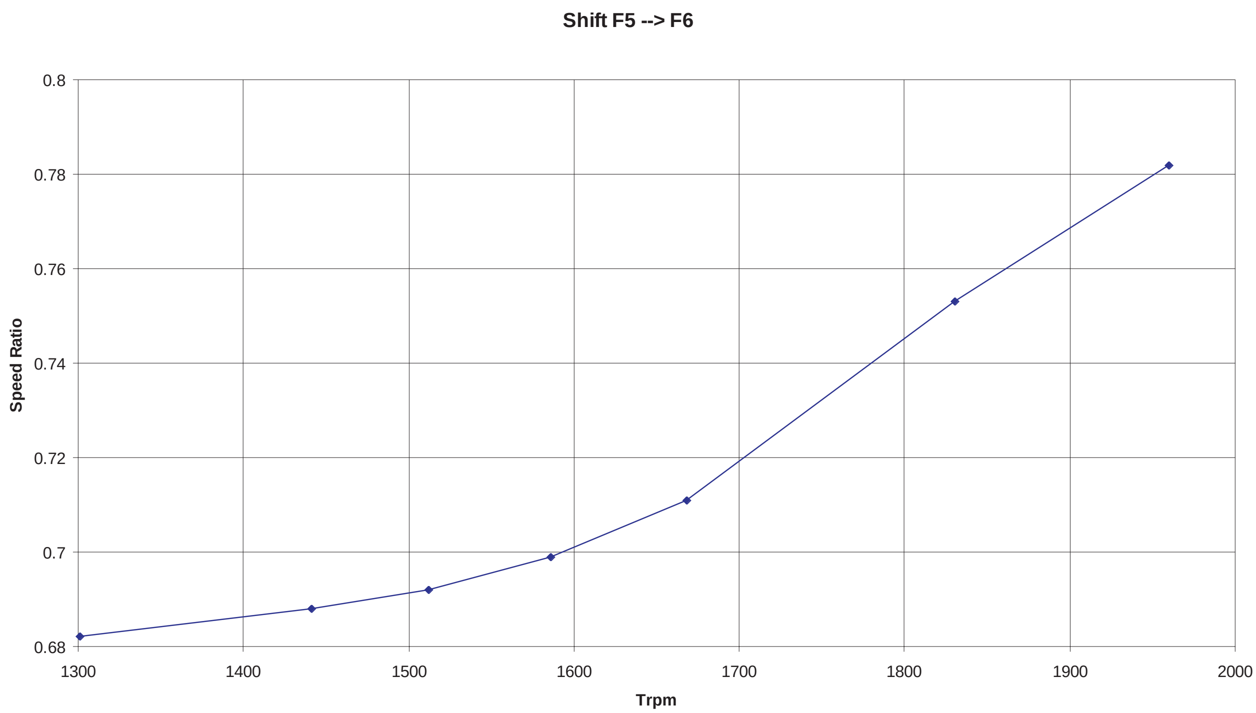
An automatic shift to a higher gear is made when the throttle pedal is pressed, the turbine speed exceeds a minimum turbine speed of 1500 RPM and the slip in the converter (speed ratio) has reached a certain value. This occurs when the tractive effort in the higher gear is higher than the tractive effort in the lower gear. The graphs below show both the upshift curve used for each gear.

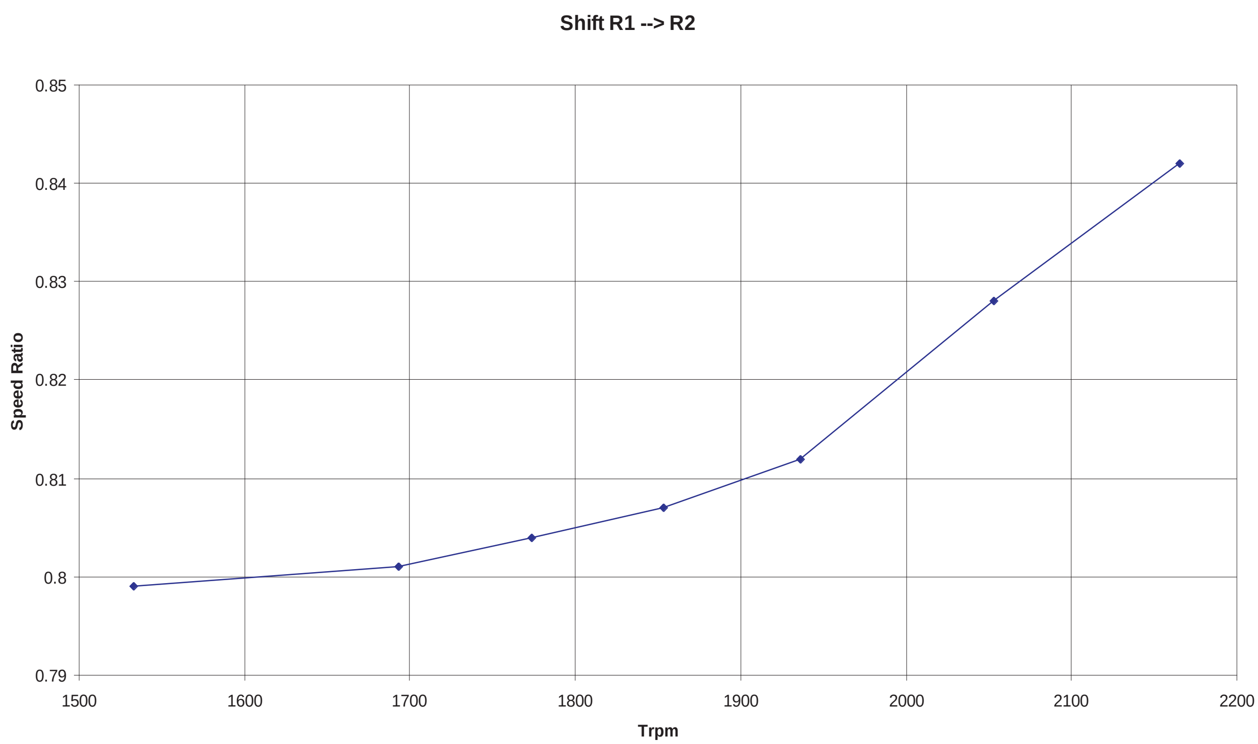



Shift F2 --> F3
Speed Ratio
0.81
0.8
0.79
0.78
0.77
0.76
0.75
0.74
0.73
1400
1500
1600
1700
1800
1900
2000
2100
Trpm

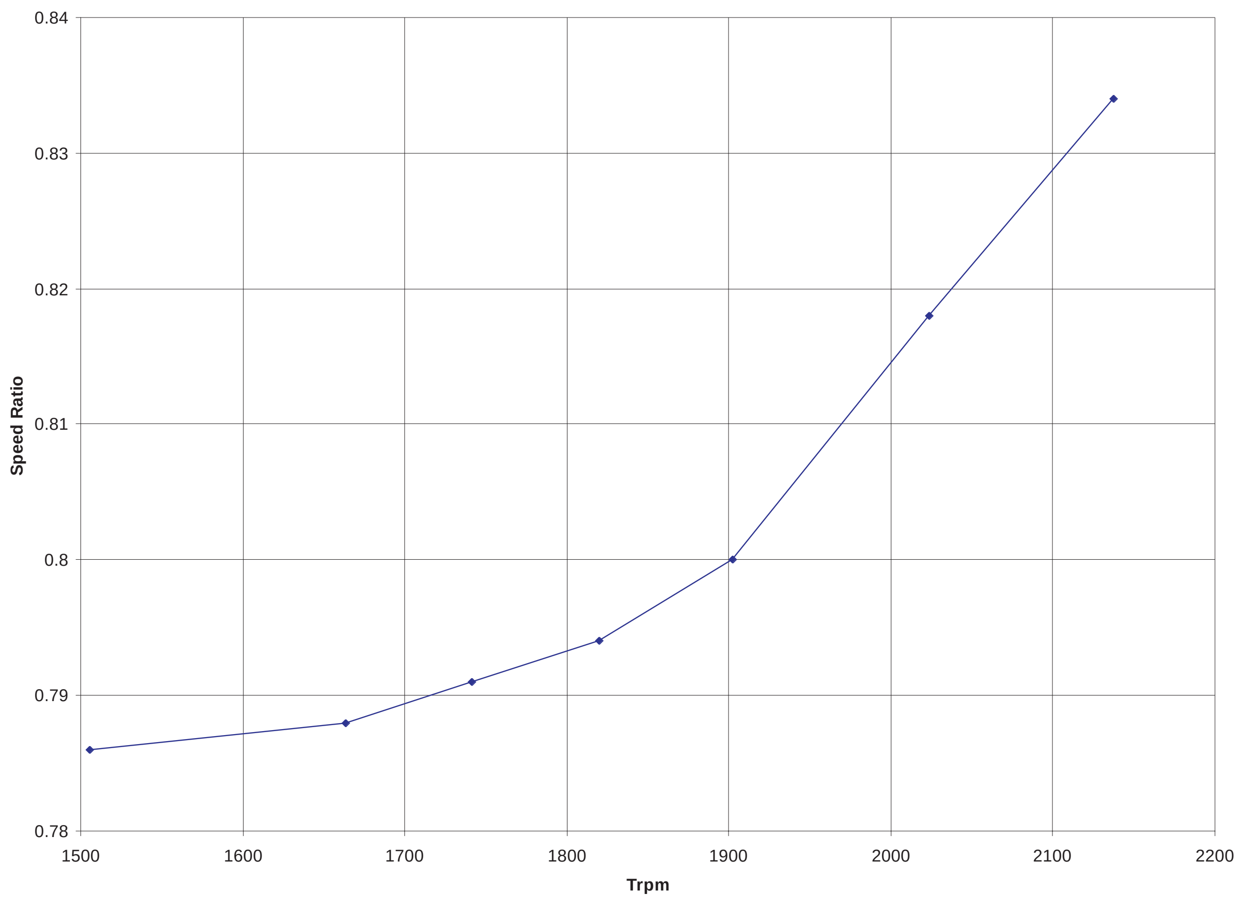

Shift F3 --> F4
Speed Ratio
0.8
0.78
0.76
0.74
0.72
0.7
0.68
1300
1400
1500
1600
1700
1800
1900
2000
Trpm


Shift F4 --> F5
Speed Ratio
0.8
0.79
0.78
0.77
0.76
0.75
0.74
0.73
0.72
0.71
1300
1400
1500
1600
1700
1800
1900
2000
2100
Trpm


Shift F5 --> F6
Speed Ratio
0.8
0.78
0.76
0.74
0.72
0.7
0.68
1300
1400
1500
1600
1700
1800
1900
2000
Trpm


Shift R1 --> R2
Speed Ratio
0.85
0.84
0.83
0.82
0.81
0.8
0.79
1500
1600
1700
1800
1900
2000
2100
2200
Trpm

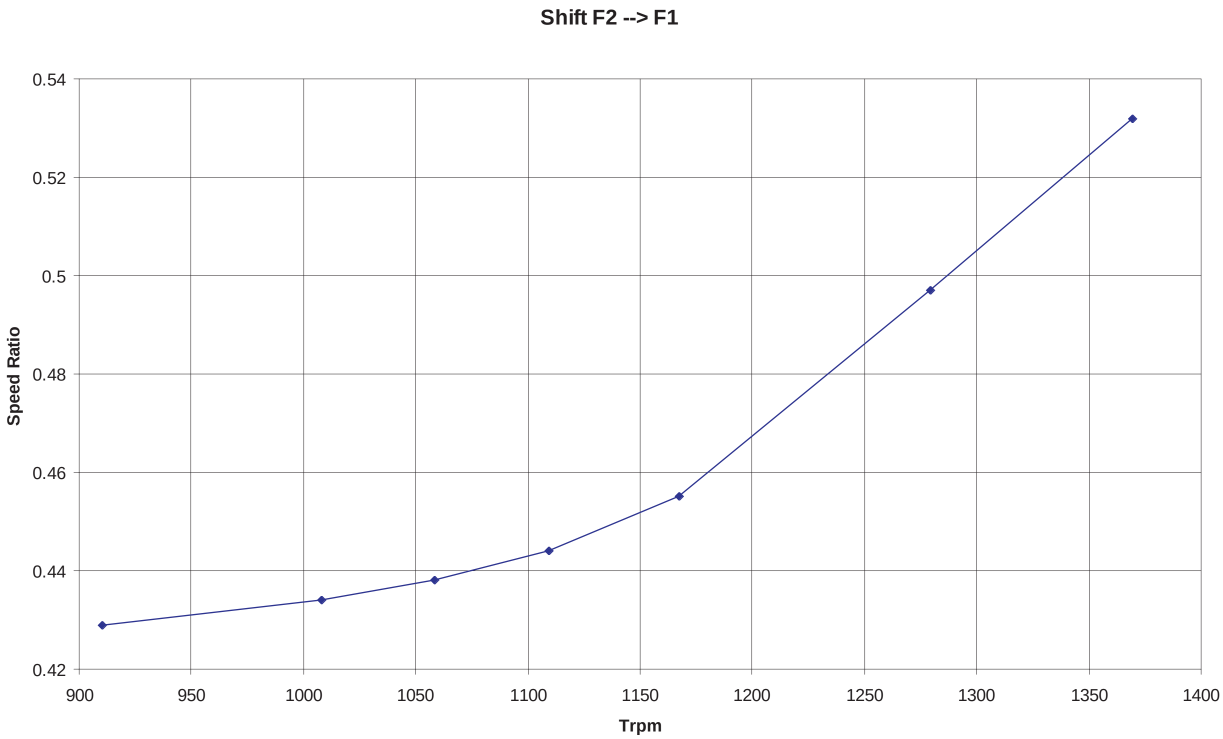
Shift R2 --> R3

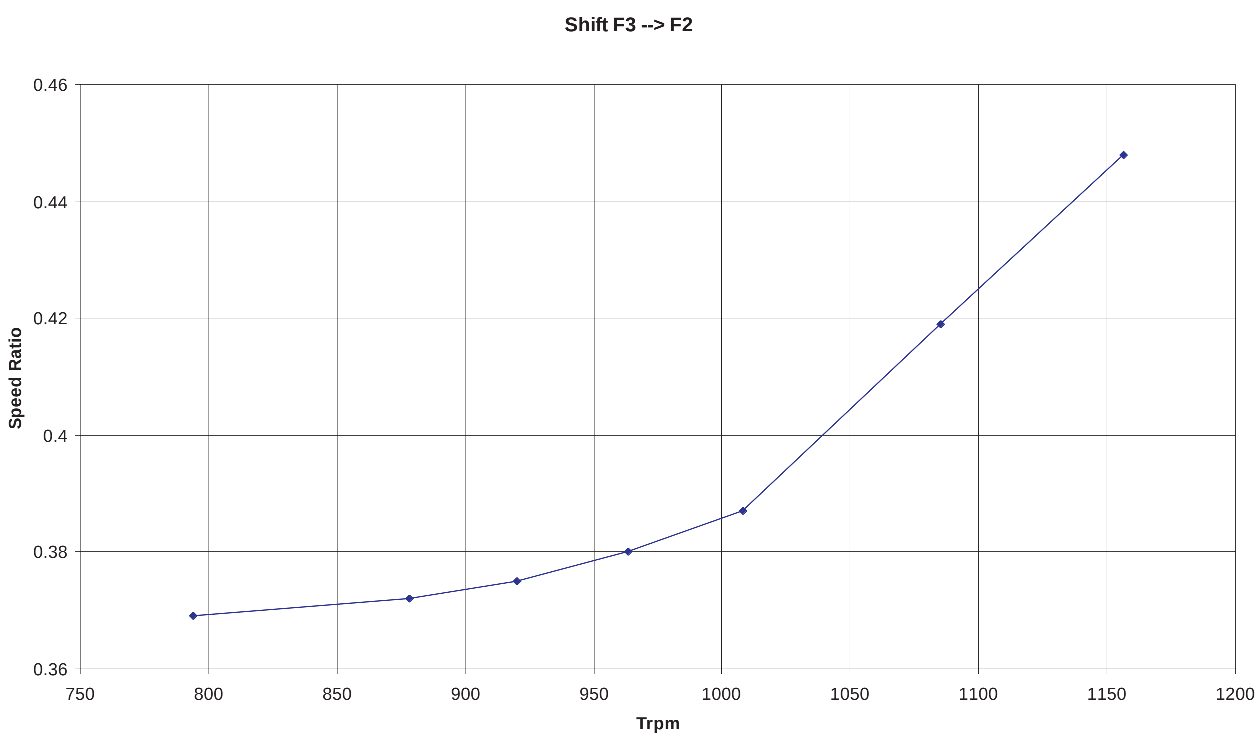


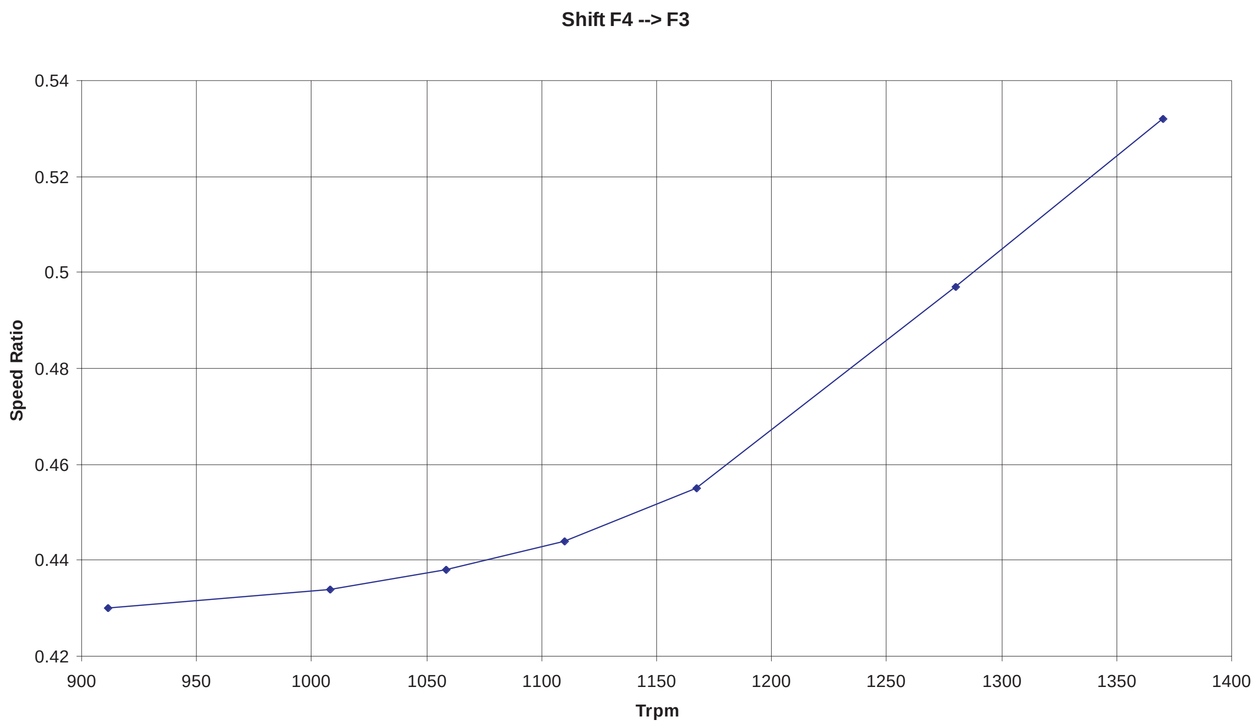
automatic downshifting

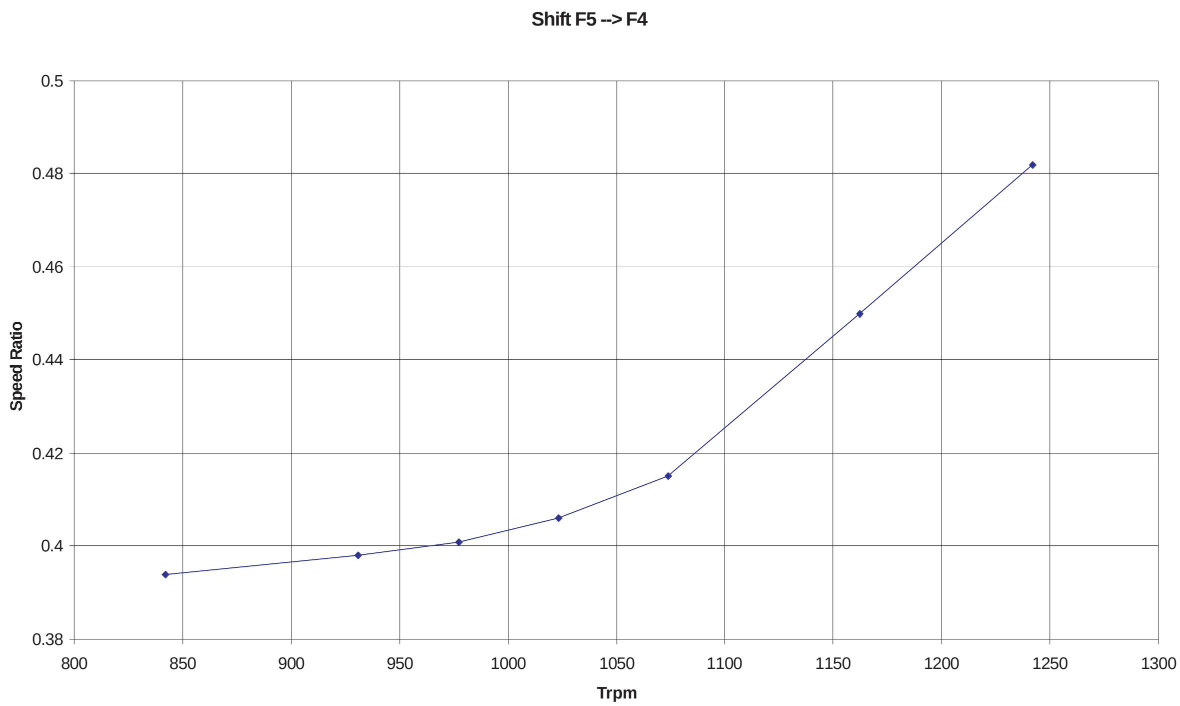
An automatic shift to a lower gear is made when the tractive effort in the lower gear exceeds the tractive effort in the higher gear.

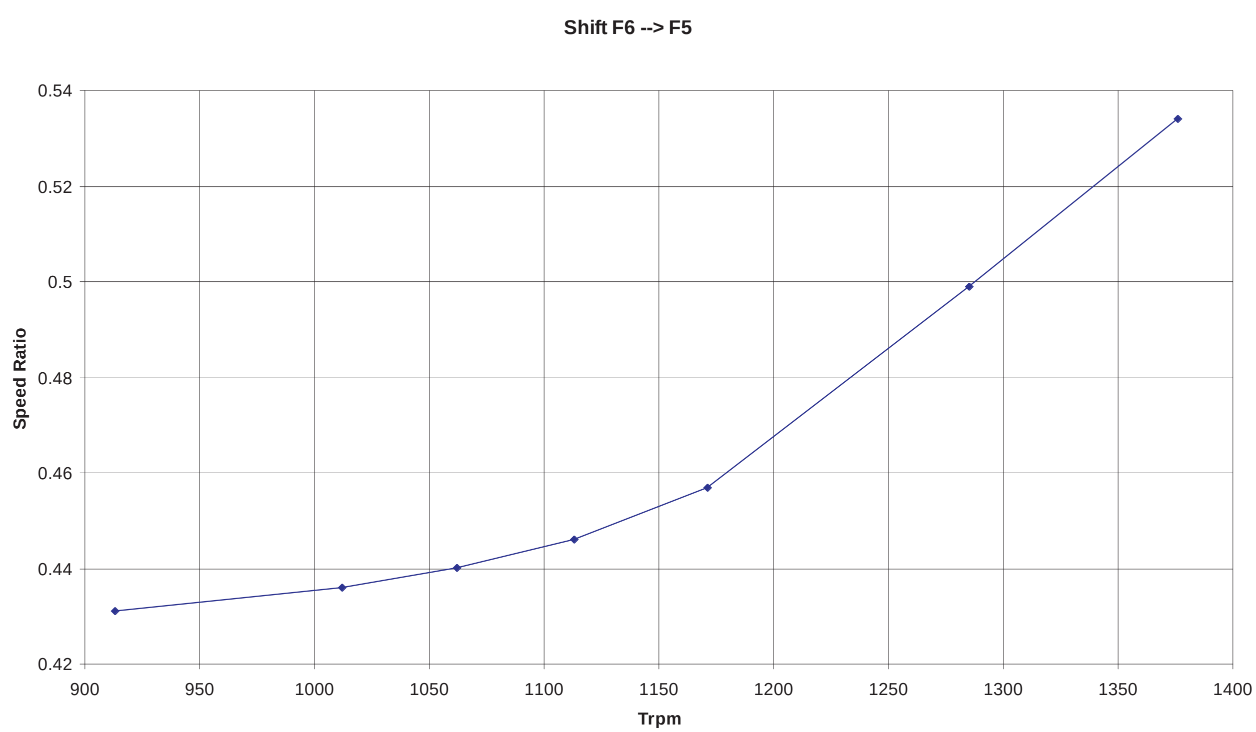
Following curves show the downshift curves for all gears.


Shift F2 --> F1
Speed Ratio
0.54
0.52
0.5
0.48
0.46
0.44
0.42
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
Trpm

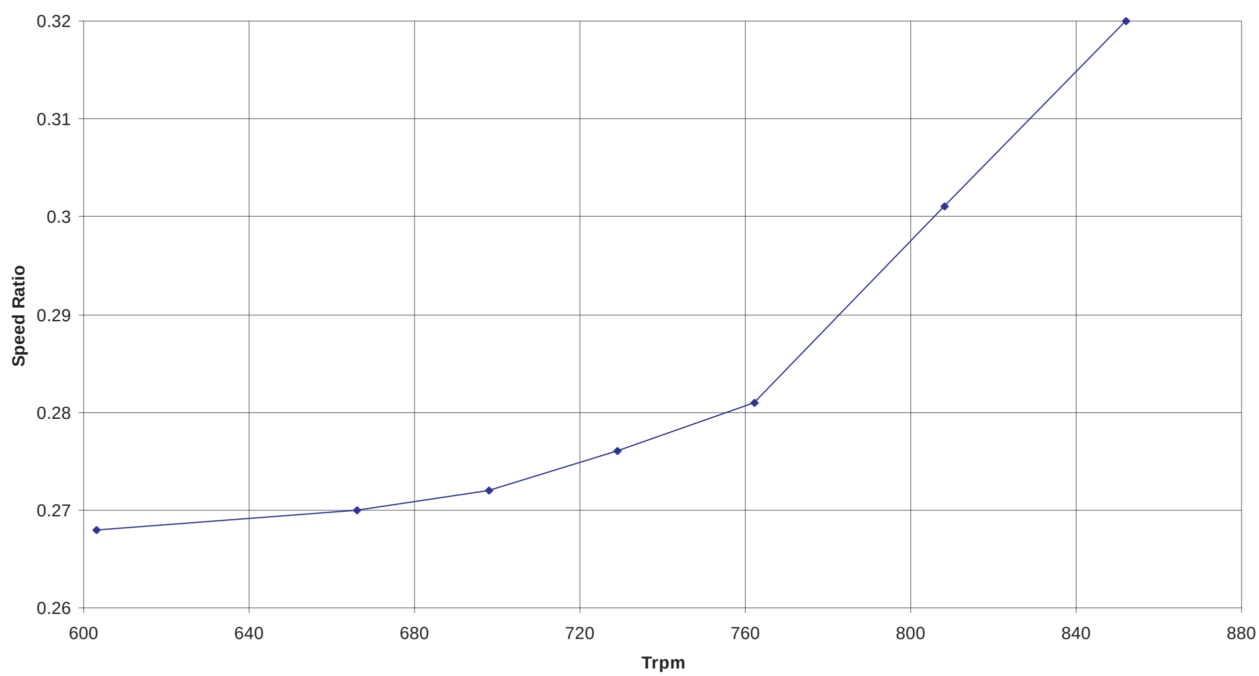

Shift F3 --> F2
Speed Ratio
0.46
0.44
0.42
0.4
0.38
0.36
750
800
850
900
950
1000
1050
1100
1150
1200
Trpm


Shift F4 --> F3
Speed Ratio
0.54
0.52
0.5
0.48
0.46
0.44
0.42
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
Trpm

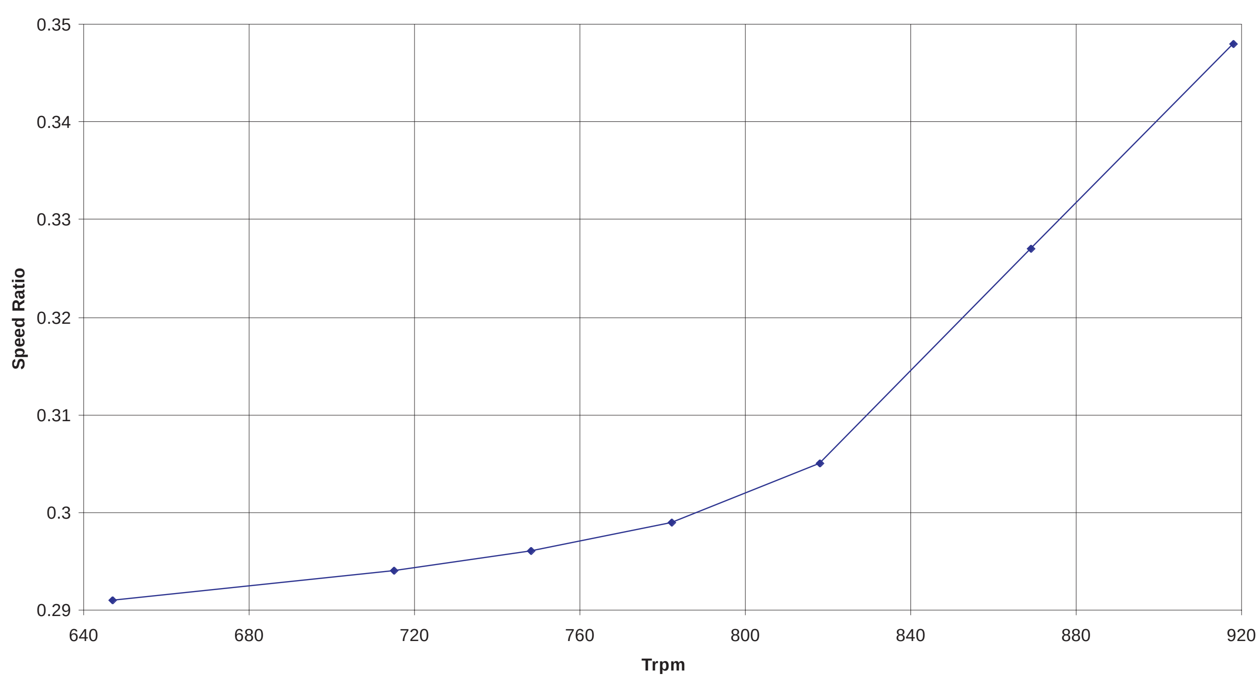

Shift F5 --> F4
Speed Ratio
0.5
0.48
0.46
0.44
0.42
0.4
0.38
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
Trpm


Shift F6 --> F5
Speed Ratio
0.54
0.52
0.5
0.48
0.46
0.44
0.42
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
Trpm

Shift R2 --> R1



Shift R3 --> R2



1.6.4.d Automatic shifting (if in 'braking mode')

automatic upshift

No automatic upshifts are allowed in braking mode (throttle pedal released). The only condition in which an upshift is made during braking mode is when the transmission overspeeding limit is reached and the shift lever indicates a gear higher than the one selected on the transmission. (see 1.6.3. Overspeeding Upshifts as transmission protection).

automatic downshift

Since the downshifts based upon speed ratio would take a very long time (because the engine speed is low), the turbine speed must be also very low before a downshift based upon speed ratio's would take place. In order to overcome this long period in which no downshift is made, braking downshifts can be incorporated in the program. When the engine speed drops below 1000 RPM and the vehicle speed drops below 500 RPM, a braking downshift is made.

1.6.4.e Lockup engagement (if in 'converter drive')

In 'idle position' of the throttle pedal (see not idle/idle switch on wire 19), lockup engages at 1650 RPM of the turbine. In 'not idle position' of the throttle pedal (see not idle/idle switch on wire 19), lockup engages at 1750 RPM of the turbine.

1.6.4.f Lockup disengagement (if in 'lockup drive')

In 'idle position' of the throttle pedal (see not idle/idle switch on wire 19), lockup disengages at 1350 RPM of the turbine. In 'not idle position' of the throttle pedal (see not idle/idle switch on wire 19), lockup engages at 1450 RPM of the turbine.

1.6.4.g Automatic upshifts (if in 'lockup drive')

Automatic upshifts in 'lockup drive' occur at 2300 RPM.

1.6.5 Output features

1.6.5.a Warning lamp output (wire 3)

When a downshift request, a forward - reverse request, a reverse - forward request, a neutral - forward request, a neutral - reverse request, a forward - neutral - forward request or reverse - neutral - reverse request is not granted due to too high vehicle speed or engine speed, or when the transmission is overspeeding, the warning lamp output (wire 3) switches on.

1.6.5.b Control valve outputs (wire 6, 7, 4, 5, 9)

Wires TC06, TC07, TC04, TC05 and TC09 are used to control the transmission. The table below reflects the gear pattern generated in each of the transmission gears.

Transmission gear	TC06	TC07	TC04	TC05	TC09
F1	●		●	●	
F2	●		●	●	●
F3	●			●	
F4	●			●	●
F5	●				
F6	●				●
N1			●	●	
N3				●	
N5					
R1		●	●	●	
R3		●		●	
R5		●			

1.7 Direction change protections

1.7.1 Forward - Reverse or Reverse - Forward

The behavior of the transmission during direction changes depends on the vehicle speed.

If the vehicle speed is below 1 km/h and the engine speed below 1000 RPM, the direction change will be executed immediately. The new gear after a direction change will be :

> 1st in automatic mode

> equal to the shift lever position in manual mode

If the vehicle speed is too high (above 1 km/h) or the engine speed is above 1000 RPM, the direction change will be not be executed and the transmission will be put in neutral until the vehicle speed has dropped below 1 km/h and the engine speed has dropped below 1000 RPM. Then the new gear after a direction change will be :

> 1st in automatic mode
> equal to the shift lever position in manual mode

1.7.2 Neutral - Forward or Neutral - Reverse

A Neutral - Forward or Neutral - Reverse action occurs when Forward or Reverse is selected out of Neutral after machine standstill. In case of a Neutral - Forward or Neutral - Reverse action, Forward or Reverse will only be put on the transmission if the engine speed is lower than 1000 RPM and the vehicle speed is lower than 1 km/h.

1.7.3 Forward - Neutral - Forward or Reverse - Neutral - Reverse

A Forward - Neutral - Forward or Reverse - Neutral - Reverse action occur if a Forward - Neutral - Forward selection or Reverse - Neutral - Reverse selection has been executed with the shiftlever and the vehicle has not been standing still in neutral.
A Forward - Neutral - Forward or Reverse - Neutral - Reverse action will only be executed if the engine speed is lower than 1000 RPM. This includes engagements following Declutch.

1.8 Downshift Protection

When a downshift is requested at high speed (in manual mode or in automatic mode) and the turbine speed would exceed the transmission limit in the lower gear (exceeding 3000 RPM), the downshift is not executed and the warning lamp switches on.

2. Safety related requirements

2.1 Applicable safety guidelines

The control system was designed and developed in close adherence to DIN/VDE801.

2.2 Safety concept

2.2.1 General

The safety concept is based on the control system's **safety classification** according to **DIN19250** and on the definition of the **Fail Safe State** for a powershift transmission used in earth moving equipment.

The applicable safety class requires considering single faults affecting driver safety and a redundant method to achieve the fail safe state in case of a single safety critical fault.

For earth moving equipment acceptable fault conditions are considered to be:

- Fail to higher range
- Fail to next lower range

The fail safe state (to be attained when all else fails) is:

- Fail to neutral

2.2.2 APC72 implementation

The transmission concept mechanically prevents simultaneously locking of two conflicting clutches and guarantees **Fail To Neutral** in case of electrical power loss.

These properties are used in the APC72 to implement the safety concept.

It monitors its inputs and outputs permanently in order to detect internal and external faults.

All faults are reported within 0.5 seconds, but only safety critical faults are acted upon.

Faults resulting in range shifts and loss of drive are tolerated.

Faults resulting in **unwanted direction clutch engagement** result in immediate selection of neutral using the available redundant shutdown method.

Some other faults are tolerated but the performance of the system is crippled when the fault persists.

2.3 Considered faults

- Over voltage
- Under voltage
- Internal faults
- Program out of control
- Single faults on outputs
- Incorrect input patterns
- Intermittent power loss
- Speed sensor failure

2.4 Behavior in case of faults

2.4.1 General

It's considered critical to be able to select Neutral in all circumstances.
Selection of Neutral is also considered the safe state in case of many faults.

The APC72 has been designed to guarantee automatic selection of Neutral in some conditions. This is accomplished through use of two separate watchdog timers and a redundant shutdown path for outputs.

2.4.2 Reset Condition

When power is applied, the APC72 first selects the highest gear and starts initializing itself. This includes a series of self tests to assure system integrity.

The highest gear is believed to be the safest possible condition in case of an intermittent power failure.

The initialization phase takes about 1 second.

After power up, the APC72 is in the so called Neutral Lock state. This means that the transmission remains in Neutral until the shift lever is cycled physically through Neutral.

2.4.3 Overvoltage

The APC72 is very tolerant to large transients on its power lines (see also 3.4).
Even power supply levels **up to 30 V** will not damage circuit components in 12V mode.
For 24V mode, supply levels can go **as high as 50V** without damaging the controller.

However in case of 12V operation a supply voltage exceeds 18Vdc, or if the 12V/24V supply input is left unconnected, the controller responds by issuing a fault and switches itself into high voltage mode until the high voltage is removed. Nevertheless, in 12V mode, the controller will accept sustained voltages up to 36 V.

In 24V mode, voltages in excess of 34V will be flagged as fault. For supply voltages in excess of 42V, the controller will protect itself by turning outputs off (or back on at even higher voltages).

2.4.4 Undervoltage

In 12V mode the APC72 operates at voltages well below 9 Vdc. To achieve this however it's important that both supply inputs are connected (12V AND 12V/24V).

Below 8Vdc however the APC72 enters the reset condition and shuts off all outputs.

For 24V operation, the same applies but the lower reliable operating voltage is 18V.
The under voltage condition is signalled as a **'battery low fault'**. The controller will not reset until the operating voltage drops below approximately 12V (but solenoids will not work well below 18V).

Because the APC72 is not involved in functions essential to engine cranking this is not considered as a problem.

2.4.5 Program out of control

The watchdog timers reset the APC72 automatically if due to a program disturbance the watchdog timers aren't reset in time (150 ms).
Additionally, during program execution, critical variables are continuously checked for contents integrity. If faults are detected, the APC72 defaults to the reset state.

2.4.6 Intermittent power loss

After power is restored, the APC72 enters the reset condition, resulting in the immediate selection of the highest gear.
In absence of power the transmission defaults to neutral. This is due to the transmission design and has nothing to do with the APC72.

2.4.7 Single faults on outputs

General

If any ON/OFF output is shorted to ground, the fault is shown on the display
but no further action is taken. The background for this is that a short on an output always results in switching the load off. This either forces Neutral or a shift to a higher range.

Direction selection related outputs (TC06,TC07) :

A short to plus is considered as a **critical fault.** Shorts to plus usually result in being blocked in either Forward or Reverse (If both are on simultaneously, the transmission behavior depends on the state of a hydro-mechanical interlock inside the transmission).

In this case, the APC72 cuts off the power to its power switches using the redundant shutdown path in order to bring the transmission to neutral (this only helps if the APC72 itself is the cause of the problem).

This response prevents the APC72 from further monitoring the outputs. Therefor once it enters this condition, it remains blocked in it until power is cycled off and on.

Other ON/OFF outputs:

Shorts to plus or open load conditions on these outputs are not considered to cause a safety hazard and are tolerated. Usually however open load conditions are mistaken for shorts to plus (due to hardware limitations) and are then treated accordingly.

The faults are indicated on the display as any output related fault.

Analogue solenoid related faults (TC03,TC08) :

Shorts to plus or ground and open load conditions on analogue outputs are not considered to cause a safety hazard and are tolerated.

Whether faults can be detected depends on the normal load of the output. If a VFS (variable force solenoid) with a coil resistance of about 4 Ohms is used, faults can reliably be detected.

A short to ground is signalled as an open circuit fault.

2.4.8 Incorrect input patterns

The shift lever pattern presented to the APC72 is continuously check for plausibility.

Direction selection related inputs:

If both Forward and Reverse are requested simultaneously, Neutral is selected.

Single 'stuck on' faults of either input are not recognized and result in a valid input signal, probably causing the 'faulty' direction to be engaged.

Range selection related inputs:

In case a shift lever pattern is generated on the inputs which does not have a matching pattern in the internal table (see 1.6.2), the pattern is ignored and the last known shift lever position is taken into consideration.

2.4.9 Speed sensor failure

An electrical speed sensor failure can be detected when using a MRS (magneto resistive sensor).
If a speed sensor fault is detected, no automatic downshifts are allowed. As soon as the error disappears, the automatic downshift is granted again.

In case of an inductive sensor, electrical fault detection on the sensor is not possible.

2.4.10 Indication of faults

When a fault is detected, the T-led starts flashing.

In order to find out which fault was last detected hold the **'M'** switch for more than 2 seconds. The display will then show alternately the fault area and the fault type. If several faults coexist, only the severest one is shown.

Below table lists faults in order of severity (severest fault on top) along with displayed codes.

Fault	Fault area	Fault Type
Direction outputs **shutdown (latched)**	Sd	
Direction outputs **forced to plus**	do	FP
Direction outputs **open connection**	do	oc
MRS Speed sensor failure **open connection**	SS	oc
MRS Speed sensor failure **short circuit**	SS	Sc
Inductive Speed sensor failure	SS	Er
Digital output **short circuit**	oU	Sc
Digital output **other fault**	oU	Er
Incorrect input pattern	In	Er

Battery voltage too low	BA	Lo
12V input voltage too high	12	Hi
12V/24V input voltage missing	no	24
24V input voltage too high	24	Hi

2.5 Behavior when faults are removed

2.5.1 Internal faults

Not applicable, because internal faults are only checked at power up

2.5.2 Program out of control

Not applicable, because this fault results in APC72 reset

2.5.3 Single faults on outputs

Fault	Response after fault removal
Short to ground	normal operation is resumed
Direction outputs : Shutdown condition	Neutral remains selected until the APC72 is reset (power off/on)
Direction outputs : Short to plus	normal operation is resumed after ±0.5 sec
Any fault on other ON/OFF outputs	normal operation is resumed

2.5.4 Incorrect input patterns

Normal operation is resumed.

2.5.5 Intermittent power loss

Not Applicable, because this fault results in APC72 reset

2.5.6 Speed sensor failure
Normal operation is resumed.

2.6 Specific measures to guarantee Fault tolerance
Operational

The control system must be installed according to the requirements and instructions stated on the appropriate customer specific wiring diagram. It shall not be operated outside the environmental conditions defined in 3.3 and 3.4.

In case a fault is signalled, the vehicle must be serviced in order to find and correct the cause of the problem.

Production Test
During the production cycle, all units receive following tests:

- Visual inspection of Printed Circuit Boards and finished product
- Functional test at nominal load and nominal power supply
- Minimum operating voltage @ 20°C is verified
- Speed sensor input function over complete operating voltage range
- Communication link test and check of programmed EEPROM parameters

Other
2.7 Measures to protect from external factors
2.7.1 Identification

Each APC72 unit is marked with a label showing following items:

- Spicer Off-Highway
- Serial Number
- Dana Spicer Off-Highway Part Number
- Program version reference

Each Printed Circuit Board shows following items:

- SOH part number of the **assembled board**,
- Board Revision Number
- Board issue date

2.7.2 Traceability and configuration control

A permanent record of above information along with other information relevant for production and service is kept in the Dana Spicer Off-Highway Bruges Controls department.

Design and implementation details of each hardware revision is available in a structured format showing following information:

- Reason for change
- Revision date, and release date
- Impact study of change
- Reference to the revision it's based on
- Circuit Diagram with changes marked
- Layout plots
- List of changes with references to the relevant drawings
- Related correspondence with manufacturer

Design and implementation details of each released software version is available in a structured format showing following information:

- Original problem analysis (or reference to it)
- Reason for change
- Revision date, and release date
- Impact study of change
- Reference to the revision it's based on
- Program source code or references to untouched modules
- List of changes with reference to reason for change
- Test report of the new release
- Related correspondence with customer

2.7.3 Sourcing

Spicer Off-Highway is the only supplier for the APC72 described in this document.

All shipped units are produced, tested and inspected by the Controls group of the Dana Spicer Off-Highway plant located in Brugge (Belgium Europe). This guarantees strict conformance to above stated identification and traceability requirements.

2.7.4 Software

Communication services are disabled during normal operation. Modifications to APC72 parameters are only possible with the shift lever in neutral.

The APC72 contains tables of boundaries limiting the range of modification of EEPROM parameters, in order to assure safe values for limits at all times.

3. Environmental conditions

3.1 Nature of environmental conditions

The APC72 is intended to be used on mobile **earth moving** and **material handling** machinery and as such is exposed to the severe environmental conditions these machines operate in.

The APC72 should be installed inside the driver's cabin, protected from direct exposure to rain, dust and direct steam cleaning.

3.2 Behavior of the system under certain conditions

The built in On/Off outputs will automatically shut off in case their junction temperature exceeds 150°C. This can be caused by external short circuits of outputs to ground, but also by over-current conditions when the unit is operated at high temperature. After cooling down, they automatically retry to drive their load.

3.3 Environmental standards and limits

Subject	Standard	Parameters
Temperature cycling	IEC68-2-14N	-40°C/80°C @ max. voltage
Power up at min. Temp.	SAEJ1455	-40°C @ min. Voltage
Power up at max. Temp.	SAEJ1455	+80°C @ min. Voltage
Humidity	IEC68-2-38	
Vibration	IEC68-68-2-34Fd	5g pk 10-150Hz 1 Oct /min 2.5Hrs 3 directions
Mechanical Shock	IEC68-68-2-29	25g ½ sine 6ms @ 1 Hz
Sealing	IEC529	IP66

3.4 Interference immunity standards and limits

Subject	Standard	Parameters 12V	Parameters 24V
Steady state voltage	SAEJ1455	9V - 16V , -40°C/80°C	18V - 32V , -40°C/80°C
Jump start requirements	SAEJ1455	5 min @ 26V, 25°C	5 min @ 50V, 25°C
Reverse polarity	SAEJ1455	5 min @ -13V, 25°C	5 min @ -26V, 25°C
Negative inductive transients	ISO7637-1/1	Vs = -100V tr=1µs td=2ms Ri=10Ω 5000 pulses Class IV	Vs = -100V tr=1µs td=2ms Ri=10Ω 5000 pulses Class IV
Positive inductive transients	ISO7637-1/2	Vs = +100V td=50µs tr=1µs Ri=10Ω 5000 pulses Class IV	Vs = +100V td=50µs tr=1µs Ri=10Ω 5000 pulses Class IV
Commutation noise	ISO7637-1/3	Vs = +100V/-150V td=100ns tr=5ns Ri=50Ω 5000 pulses pos and neg Class IV	Vs = +100V/-150V td=100ns tr=5ns Ri=50Ω 5000 pulses pos and neg Class IV
Voltage drop	ISO7637-1/4		
Load Dump	ISO7637-1/5	Vs =+86.5V td=350ms tr=5ms Ri=3Ω Class IV	Vs =+226V td=350ms tr=5ms Ri=5Ω Class IV
Electrostatic discharge	IEC801-2	air discharge 8 kV Class III contact discharge 4kV Class III	air discharge 8 kV Class III contact discharge 4kV Class III
Radiated interference	ISO/ CD13766	Parameters as per standard	Parameters as per standard

4. Development requirements

4.1 Special requirements for design and implementation

Conformance with European directive 89/336.

A Technical Construction File must prove close adherence to all requirements laid down in draft standard **ISO/CD 13766**

Misapplication of voltage: any one pin must tolerate short circuit to plus or ground at nominal operating voltage.

4.2 Design and development tools

The control system hardware was designed with development tools purchased from PADS inc. Schematic entry is done with PADS Logic. Printed Circuit Design occurs with PADS Perform.

About 80% of the software is written in PLM-51 (Intel © High Level language for 80C51 compatible products). The remaining 20 % are written in INTEL ASM-51, the largest part of it being a library of 32-bit integer math functions, which have been used for 6 years in comparable applications.

The Hardware / Software combination is tested using Ashling CTS51 in circuit emulators.

5. Guidelines and Conditions for Use

5.1 Diagnostics and maintenance

5.1.1 General

Principally there are no specific devices required for first level troubleshooting as the APC72 incorporates several self-test features assisting in this process.

Nevertheless, use of digital multi-meters and simple tools such as an indicator lamp will be required to pinpoint exact causes of problems.

More in depth troubleshooting and system tuning involves use of an IBM Compatible PC with appropriate software and EPROM programming equipment.

The APC72 allows recall and modification of non-volatile parameters through RS232.

This way, customers can (given the necessary equipment) choose to adapt certain parameters to suit their needs.

From a maintenance point of view, this is relevant in so far that the APC72 allows reading back the (modified) parameters along with serial number, part number and modification date.

5.1.2 Self test Functions

The APC72 has special circuitry to help verifying its operation.

Four self-test modes are built into the APC72 control programs:

- Turbine speed monitor
- Engine speed monitor
- Speed ratio monitor
- Speed Ratio Up
- Speed Ratio Down
- Battery voltage monitor
- Input Test
- Output Test
- ANalog Input Monitor

The 'T' led is on while operating the APC72 in test mode.

Depending on the application, it's possible that additional test modes are supported.

5.1.2.a Self test Operation

Self-test mode is activated by pressing the mode switch on the APC72 front panel while powering up the APC72.

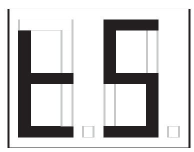
Switching off the power of the APC72 leaves the self-test mode.

After powering up, the **turbine speed monitor** is activated.

Pushing the mode switch after powering up selects the next mode in the order listed above. After output test, turbine speed monitoring is again selected.

5.1.2.b Turbine Speed Monitor

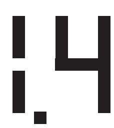
When selecting this mode the display shows:



After releasing the mode switch the display shows turbine speed in RPM (rotations per minute).

From 0 - 999 rpm the display displays 10's - i.e. below display corresponds with 630 RPM.

From 1000 RPM on, the display shows thousands. The example indicates 1400 RPM



5.1.2.c Engine Speed Monitor

When selecting this mode the display shows:

After releasing the mode switch the display shows engine speed in RPM (rotations per minute).

The display method is identical as described above for turbine speed.

5.1.2.d Speed ratio Monitor

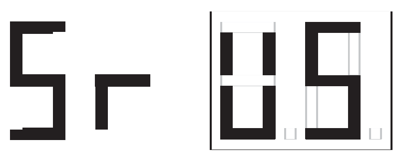
When selecting this mode the display shows:

After releasing the mode switch the display shows the speed ratio in the converter.

$$\text{speed ratio} = \frac{\text{turbine speed}}{\text{engine speed}} < 1$$

5.1.2.e Upshift Speed ratio

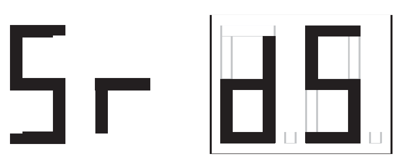
When selecting this mode the display shows:



The value indicates the theoretical optimal upshift speed ratio. See also upshift curve(s) shown earlier.

5.1.2.f Downshift Speed ratio

When selecting this mode the display shows :



The value indicates the theoretical optimal downshift speed ratio. See also downshift curve(s) shown earlier.

5.1.2.g Battery Voltage Monitor

When selecting this mode the display shows:

The voltage displayed is measured on the 12V/24V input i.e. on pin TC01.

The displayed value after the mode switch is released is the battery voltage in **Volts**.

Values with a fractional part of 0.5V or higher have the right dot on

	Voltage range : 13.0 V - 13.4 V
	Voltage range : 13.5 V - 13.9 V

5.1.2.h Input Test

When selecting this mode the display shows:

This test is used to verify operation of the shift lever and other inputs.

The display shows which inputs are active. The driver (or technician) can follow the sequence of inputs and thus verify the wiring of the vehicle. Each segment of the display indicates a specific input. Different segments can be switched on simultaneously if different inputs are activated simultaneously.

This segment is switched on if input wire TC13 is activated (Shiftlever F).

This segment is switched on if input wire TC14 is activated (Shiftlever R).

This segment is switched on if input wire TC25 is activated (Shiftlever range).

This segment is switched on if input wire TC15 is activated (Shiftlever range).

This segment is switched on if input wire TC18 is activated (Shiftlever range).

This segment is switched on if input wire TC29 is activated (Man/Automatic).

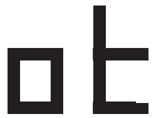
This segment is switched on if input wire TC19 is activated (Not idle/Idle).

This segment is switched on if input wire TC22 is activated (Lockup).

Input wire TC19 and wire TC22 are both activated.

5.1.2.i Output test

When selecting this mode the display shows:



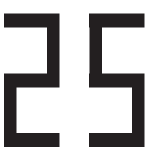
This mode can only be selected at standstill. When pressing the mode switch while driving or if a speed sensor fault is flagged, this mode is skipped.

After operating in this test mode, the transmission is blocked in neutral until the shift lever is cycled through its neutral position.

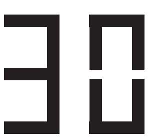
The APC72 gives information about the status of the outputs. The possible states are: G (good), S (short-circuit with ground) and O (open load : output is not connected or has a short-circuit to the battery plus).

The APC72 tests each output sequentially, the left side of the display gives information about which output is tested, the right side gives the status of the output.

OUTPUT 1 is good.



OUTPUT 2 has a short circuit to ground.



OUTPUT 3 is not connected or has a short circuit to battery +.

Each output corresponds to a specific output wire.

Output	Function	Wire	Normal Display
1	Forward	TC06	'1G'
2	Reverse	TC07	'2G'
3	Solenoid 1	TC04	'3G'
4	Solenoid 2	TC05	'4G'
5	Solenoid 3	TC09	'5G'
8	PWM0 Solenoid supply.	TC03	'8G'

5.1.2.j Analog Input Monitor

When selecting this mode the display shows:

The displayed value after the mode switch is released is the resistance of the respective analogue input. In this case analog input 0 is wire 30.

5.2 Technical guidelines for installation

The information contained in this section is provided to ease the installation of the APC72 on the vehicle.

The main part of the installation concerns connecting APC72 wiring harness with the Transmission's control valve harness and to the shift lever. Below tables show the pin functions for the control valve harness and which connections are required between control valve and APC72.

Transmission Control Valve connections

Wire	Color	Pin	Function
7	Brown	A	Reverse
5	Green	B	Solenoid 2
4	Yellow	C	Solenoid 1
9	Orange	D	Common
6	Blue	E	Forward
11	Pink	F	Splitter Solenoid

5.2.1 Power supply

Positive terminals TC01 / TC11

For 24V operation **only terminal TC01** shall be connected to the battery plus.

Connecting TC11 also to 24V can damage the APC72 and will be flagged as a severe fault continuously.

On the other hand, 12V operation requires that the battery plus is connected to **both TC01 and TC11**. Failure to connect to TC11 will be flagged as a warning and increases the minimum operating voltage to approximately 11 Volts.

Wires TC01 (and TC11 if applicable) must be connected to the battery through a **fast** 6 Amp fuse. They provide power for the shift logic and for the outputs which control the transmission solenoids.

Analogue Solenoid supply TC10

This terminal is a special **on/off output.** It should be connected **only** to solenoids connected to TC03 and TC08. It provides specially conditioned power to both analogue modulation solenoid outputs.

For wire lengths greater than 4 m it's recommended to use a twisted triple in order to minimize radiated emissions from these wires.

A twisted triple is a cable consisting of 3 parallel wires twisted together with roughly 60 turns per meter. The three cables involved are those coming from TC10, TC03 and TC08.

Ground terminal TC02

Pin TC02 is the APC72's ground terminal and must be connected to a well-defined ground terminal. This can be the vehicle's chassis or an AWG16 wire routed straight to the battery minus.

For the APC72 control to work properly, a T-split of the ground wire (close to the connector) must be made to form a suitable ground reference for the Control Valve.

Ground terminal TC12

Pin TC12 is the **signal ground** terminal and is intended for following signals

- Speed sensor ground for TC21 and TC23
- Analogue inputs TC20 and TC30
- Communication link ground (CAN and RS232, RS485)

5.2.2 Input signals

Shift lever inputs (TC13, TC14,TC25,TC15,TC18)

The common terminal of the shift lever is to be connected to the plus (TC01).

The expected pattern on these inputs is described in 1.6.2. Shiftlever.

Inductive Turbine Speed sensor input (TC23)

TC23 must be connected to the inductive sensor's terminal. The other terminal should be connected to TC12.

TC24 (MRS input) must be left **unconnected.**

Inductive Engine Speed sensor input (TC21)

TC21 must be connected to the inductive engine speed sensor's terminal. The other terminal should be connected to TC12.

5.2.3 Output signals

These signals control the selection of direction and range. See also 1.6.5.

5.2.4 Communication interfaces

5.2.4.a Can link (TC28,TC17): interface

This interface complies electrically with ISO11898.

Although the system is capable of handling CAN 2A messages, it is not an issue in the current application.

It is foreseen to ease future system extensions beyond the scope of this specification.

5.2.4.b Tuning Link (TC08,TC28)

The communication protocol is RS232 compatible and is intended for use with existing Spicer Off-Highway Tuning tool and is reserved for Spicer Off-Highway use only.

6. Revision Record

Revision	Date made	Comments
G10	03/12/02	Startup version
G11	6Apr04	Added Declutch request on Wire 30 and added Analog Input Monitor in diagnostics.