NCV78703

Multiphase Booster LED Driver for Automotive Front Lighting

The NCV78703 is a single−chip and high efficient booster for smart Power ballast and LED Driver designed for automotive front lighting applications like high beam, low beam, DRL (daytime running light), turn indicator, fog light, static cornering, etc. The NCV78703 is in particular designed for high current LEDs and with NCV78723 (dual channel buck)/713 (single channel) provides a complete solution to drive multiple LED strings of up−to 60 V. It includes a current−mode voltage boost controller which also acts as an input filter with a minimum of external components. The available output voltage can be customized. Two devices NCV78703 can be combined and the booster circuits can operate together to function as a multiphase booster (2−phase, 3−phase, 4−phase, 5−phase, 6−phase) in order to further optimize the filtering effect of the booster and lower the total application BOM cost for higher power. Thanks to the SPI programmability, one single hardware configuration can support various application platforms.

Features

- Single Chip
- Multiphase Booster
- High Overall Efficiency
- Minimum of External Components
- Active Input Filter with Low Current Ripple from Battery
- Integrated Boost Controller
- Programmable Input Current Limitation
- High Operating Frequencies to Reduce Inductor Sizes
- PCB Trace for Current Sense Shunt Resistor is Possible
- Low EMC Emission
- SPI Interface for Dynamic Control of System Parameters
- Fail Save Operating (FSO) Mode, Stand−Alone Mode
- Integrated Failure Diagnostic

Typical Applications

- High Beam
- Low Beam
- DRL
- Position or Park Light
- Turn Indicator
- Fog
- Static Cornering

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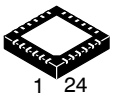
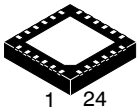


QFN24
MW SUFFIX
CASE 485L



QFN24
MW SUFFIX
CASE 485CS

MARKING DIAGRAM

Case 485L

Case 485CS

N703 or N78703 = Specific Device Code
A = Assembly Location
L or WL = Wafer Lot
Y or YY = Year
W or WW = Work Week
▪ = Pb−Free Package

(Note: Microdot may be in either location)

ORDERING INFORMATION

See detailed ordering and shipping information on page 34 of this data sheet.

TYPICAL APPLICATION SCHEMATIC

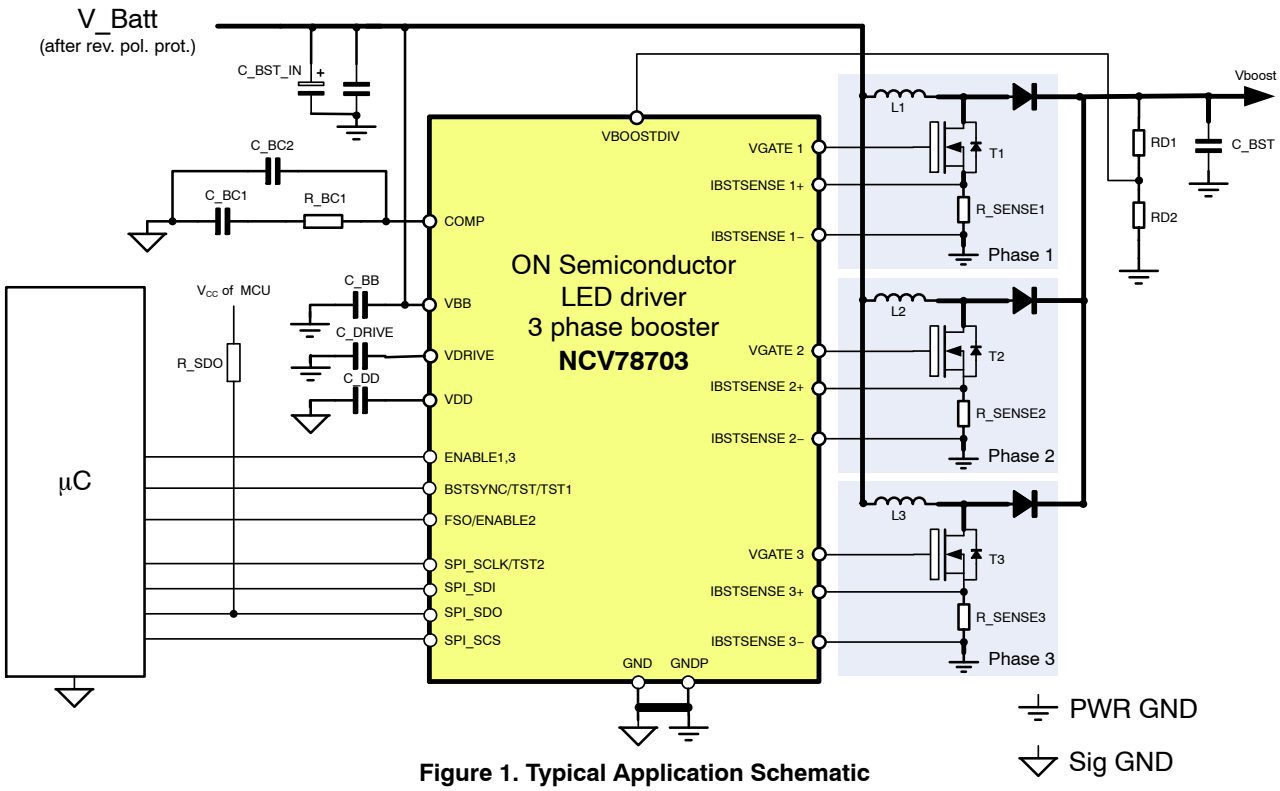


Figure 1. Typical Application Schematic

Table 1. EXTERNAL COMPONENTS

Component	Function	Typ. Value	Unit
L1, L2, L3	Booster regulator coil	10	μH
T1, T2, T3	Booster regulator switching transistor	e.g. NTD6416ANL	
D1, D2, D3	Booster regulator diode	e.g. MBR5H100MFS	
R_SENSE1, R_SENSE2, R_SENSE3	Booster regulator current sensing resistor	10	mΩ
C_BST	Booster regulator output capacitor	0.44	μF/W
C_BB	V_{BB} decoupling capacitance (Note 1)	1	μF
C_VDRIVE	Capacitor for V_{DRIVE} regulator	1	μF
C_VDRIVE_ESR	ESR of V_{DRIVE} capacitor	max. 200	mΩ
C_DD	V_{DD} decoupling capacitor	1	μF
C_DD_ESR	ESR of V_{DD} capacitor	max. 200	mΩ
R_SDO	SPI pull−up resistor	1	kΩ
C_BC1	Booster compensation network	See Booster Compensator Model section	
C_BC2	Booster compensation network	See Booster Compensator Model section	
R_BC1	Booster compensation network	See Booster Compensator Model section	
RD1	Booster output voltage feedback divider (Note 2)	107 (±1% tolerance)	kΩ
RD2	Booster output voltage feedback divider (Note 2)	3.24 (±1% tolerance)	kΩ

1. The value represents a potential initial startup value on a generic application. The actual size of the boost capacitor depends on the application defined requirements (such as power level, operating ranges, number of phases) and transient performances with respect to the rest of BOM. Please refer to application notes and tools provided by ON Semiconductor for further guidance. The chosen value must be validated in the application.
2. Proposed values. Divider ratio (BSTDIV_RATIO) has to be 34. Tolerance of the resistors has to be ±1% to guarantee Booster parameters (see Table 12).

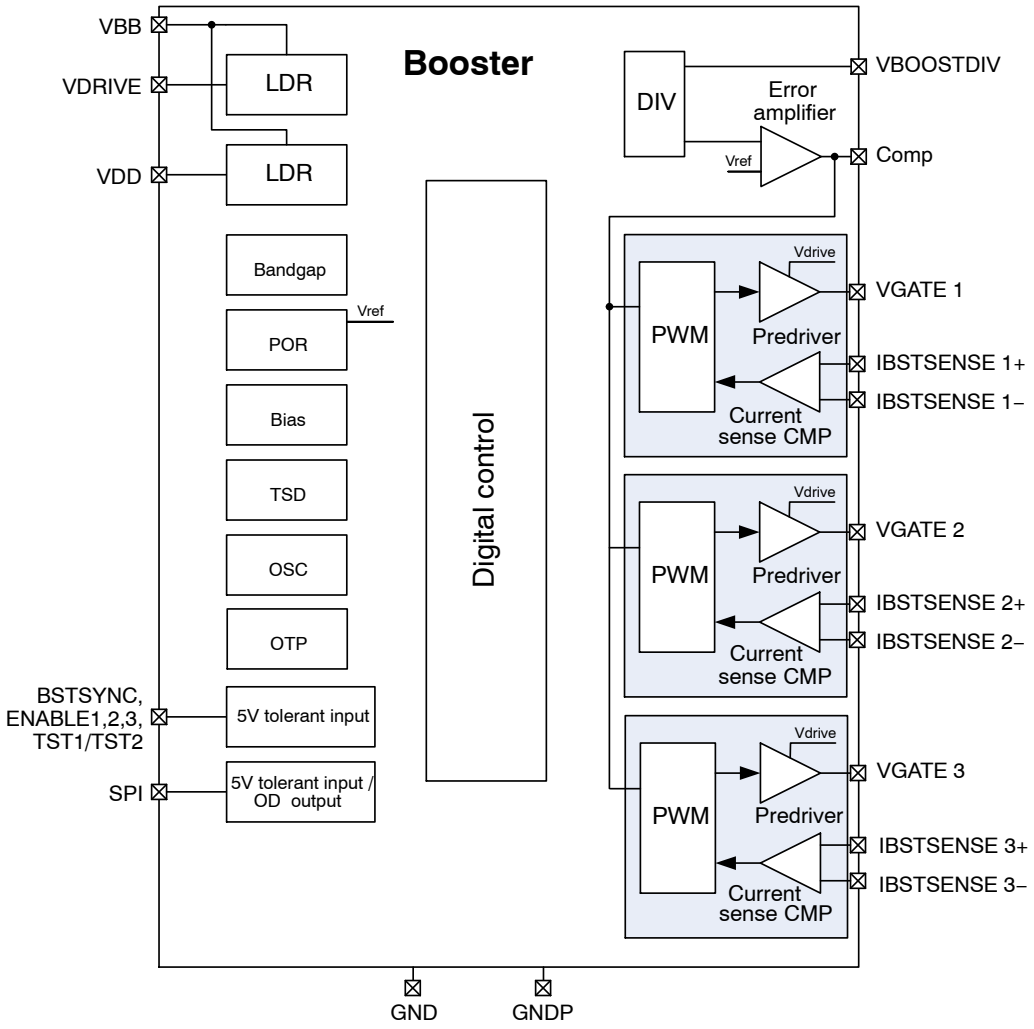


Figure 2. Block Diagram

PACKAGE AND PIN DESCRIPTION

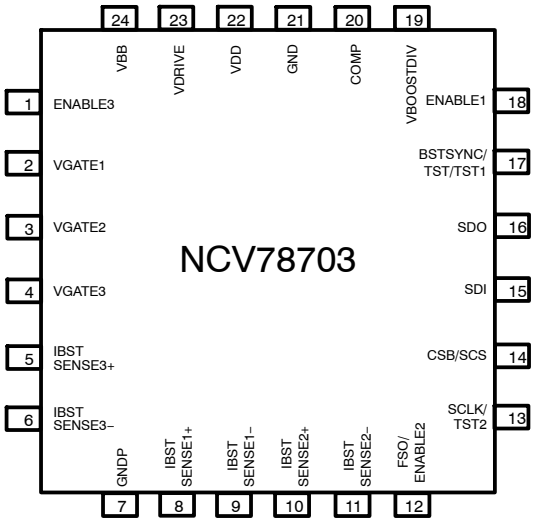


Figure 3. Pin Connections – QFN24 5x5 and QFN24 4x4

Table 2. PIN DESCRIPTION

Pin No. QFN24	Pin Name	Description	I/O Type
1	ENABLE3	ENABLE3 input	MV in
2	VGATE1	Booster MOSFET gate pre−driver	MV out
3	VGATE2	Booster MOSFET gate pre−driver	MV out
4	VGATE3	Booster MOSFET gate pre−driver	MV out
5	IBSTSENSE3+	Coil3 current positive feedback input	MV in
6	IBSTSENSE3−	Coil3 current negative feedback input	MV in
7	GNDP	Power ground	Ground
8	IBSTSENSE1+	Coil1 current positive feedback input	MV in
9	IBSTSENSE1−	Coil1 current negative feedback input	MV in
10	IBSTSENSE2+	Coil2 current positive feedback input	MV in
11	IBSTSENSE2−	Coil2 current negative feedback input	MV in
12	FSO/ENABLE2	FSO/ENABLE2 input	MV in
13	SCLK/TST2	SPI clock / TST2 IO	MV in
14	CSB/SCS	SPI chip select (chip select bar)	MV in
15	SDI	SPI data input	MV in
16	SDO	SPI data output – pull up	MV open−drain
17	BSTSYNC/TST/TST1	External clock for the boost regulator/ TM entry/ TST1 IO	HV in
18	ENABLE1	ENABLE1 input	MV in
19	VBOOSTDIV	Booster high voltage feedback input	HV in
20	COMP	Compensation for the Boost regulator	LV in/out
21	GND	Ground	Ground
22	VDD	3 V logic supply	LV supply
23	VDRIVE	10 V supply	MV supply
24	VBB	Battery supply	HV supply

Table 3. ABSOLUTE MAXIMUM RATINGS

Characteristic	Symbol	Min	Max	Unit
Battery supply voltage (Note 4)	V_{BB}	−0.3	36 (Note 3)	V
Logic supply voltage (Note 5)	V_{DD}	−0.3	3.6	V
Gate driver supply voltage (Note 6)	V_{DRIVE}	−0.3	12	V
Input current sense voltage (Note 7)	IBSTSENSEPx, IBSTSENSENx	−1.0	12	V
Medium voltage IO pins (Note 8)	IOMV	−0.3	6.5	V
Storage Temperature (Note 9)	T_{STRG}	−50	150	°C
Electrostatic Discharge on Component Level (Note 10) Human Body Model Charge Device Model	 V_{ESD_HBM} V_{ESD_CDM}	 −2 −500	 +2 +500	 kV V

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

3. Absolute maximum rating for VBB is 40 V for limited time < 0.5 s
4. Absolute maximum rating for pins: VBB, BSTSYNC/TST/TST1, VBOOSTDIV
5. Absolute maximum rating for pins: VDD, COMP
6. Absolute maximum rating for pins: VDRIVE, VGATE1, VGATE2, VGATE3
7. Absolute maximum rating for pins: IBSTSENSE1+, IBSTSENSE1−, IBSTSENSE2+, IBSTSENSE2−, IBSTSENSE3+, IBSTSENSE3−
8. Absolute maximum rating for pins: SCLK/TST2, CSB, SDI, SDO, ENABLE1, FSO/ENABLE2, ENABLE3
9. For limited time up to 100 hours. Otherwise the max storage temperature is 85°C.
10. This device series incorporates ESD protection and is tested by the following methods:
    ESD Human Body Model tested per EIA/JESD22−A114
    ESD Charge Device Model tested per ESD−STM5.3.1−1999
    Latch−up Current Maximum Rating: ≤100 mA per JEDEC standard: JESD78

Operating ranges define the limits for functional operation and parametric characteristics of the device. A mission profile (Note 11) is a substantial part of the operation conditions; hence the Customer must contact ON Semiconductor in order to mutually agree in writing on the allowed missions profile(s) in the application.

Table 4. RECOMMENDED OPERATING RANGES

Characteristic	Symbol	Min	Typ	Max	Unit
Battery supply voltage (Note 12 and 13)	V_{BB}	5		30	V
Logic supply voltage (Note 14)	V_{DD}	3.1		3.5	V
VDD current load	I_{DD}			50	mA
Medium voltage IO pins	IOMV	0		5	V
Input current sense voltage	IBSTSENSEPx, IBSTSENSENx	−0.1		1	V
Functional operating junction temperature range (Note 15)	T_{JF}	−45		155	°C
Parametric operating junction temperature range (Note 16)	T_{JP}	−40		150	°C

Functional operation above the stresses listed in the Recommended Operating Ranges is not implied. Extended exposure to stresses beyond the Recommended Operating Ranges limits may affect device reliability.

11. A mission profile describes the application specific conditions such as, but not limited to, the cumulative operating conditions over life time, the system power dissipation, the system's environmental conditions, the thermal design of the customer's system, the modes, in which the device is operated by the customer, etc. No more than 100 cumulated hours in life time above T_{tw}.
12. Minimum V_{BB} for OTP memory programming is 15.8 V.
13. VDRIVE is supplied from VBB, it must be verified that VDRIVE voltage is appropriate for the external FETs.
14. VBB > 5 V
15. The circuit functionality is not guaranteed outside the functional operating junction temperature range. Also please note that the device is verified on bench for operation up to 170°C but that the production test guarantees 155°C only.
16. The parametric characteristics of the circuit are not guaranteed outside the Parametric operating junction temperature range.

Table 5. THERMAL RESISTANCE

Characteristic	Package	Symbol	Min	Typ	Max	Unit
Thermal Resistance Junction to Exposed Pad (Note 17)	QFN24 4x4	Rthjp		2.82		°C/W

17. Includes also typical solder thickness under the Exposed Pad (EP). Thermal resistance junction to PCB Top Layer.

ELECTRICAL CHARACTERISTICS

Note: All Min and Max parameters are guaranteed over full battery voltage (5 V; 30 V) and junction temperature (T_{JP}) range (−40°C; 150°C), unless otherwise specified.

Table 6. TEMPERATURE MEASUREMENTS

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
Thermal Shutdown	TSD		165	170	175	°C
Thermal Warning	TW		155	160	165	°C
Thermal Output	TEMP7	ADC_TEMP_THR[2:0] = 111	140	150	160	°C
Thermal Output	TEMP6	ADC_TEMP_THR[2:0] = 110	130	140	150	°C
Thermal Output	TEMP5	ADC_TEMP_THR[2:0] = 101	120	130	140	°C
Thermal Output	TEMP4	ADC_TEMP_THR[2:0] = 100	110	120	130	°C
Thermal Output	TEMP3	ADC_TEMP_THR[2:0] = 011	100	110	120	°C
Thermal Output	TEMP2	ADC_TEMP_THR[2:0] = 010	90	100	110	°C
Thermal Output	TEMP1	ADC_TEMP_THR[2:0] = 001	80	90	100	°C
Thermal Output	TEMP0	ADC_TEMP_THR[2:0] = 000	70	80	90	°C
Thermal Output Hysteresis	TEMP_HYST			3		°C

Table 7. VDRIVE: 10 V SUPPLY FOR BOOST FET GATE DRIVER CIRCUIT

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
VDRIVE reg. voltage from VBB (Note 18)	VDRV_15	[VDRIVE_VSETPOINT = 1111], Vbb − VDRIVE > 0.5 V @IDRIVE = 90 mA	9.7	10.1	10.7	V
VDRIVE reg. voltage from VBB (Note 18)	VDRV_00	[VDRIVE_VSETPOINT = 0000], Vbb − VDRIVE > 0.5 V @IDRIVE = 90 mA	4.8	5	5.3	V
VDRIVE increase per code (Note 18)	ΔVDRV	Linear increase, 4 bits		0.34		V
DC output current consumption	VDRV_ILIM		0		90	mA
Output current limitation	VDRV_BB_IL		90		500	mA
Output overload condition for VDRIVE_NOK detection (Note 19)	VDRIVE_NOK_ILOAD		95			mA
Minimum VBB−VDRIVE sufficient voltage (Note 19)	VDRIVE_NOK_VBBLOW		0.5			V
VDRIVE UV detection threshold (Note 20)	VDRV_UV_[7]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 111]	83	87	91	%
VDRIVE UV detection threshold (Note 20)	VDRV_UV_[6]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 110]	79	83	87	%
VDRIVE UV detection threshold (Note 20)	VDRV_UV_[5]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 101]	75	79	84	%
VDRIVE UV detection threshold (Note 20)	VDRV_UV_[4]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 100]	71	75	79	%
VDRIVE UV detection threshold (Note 20)	VDRV_UV_[3]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 011]	63	67	71	%

18. The VDRIVE voltage drop between VDRIVE and VBB has to be sufficient (min. 0.5 V).
19. Both of these conditions have to be fulfilled otherwise SPI status bit VDRIVE_NOK is set.
20. Relative threshold to typical value of VDRIVE_VSETPOINT settings.

Table 7. VDRIVE: 10 V SUPPLY FOR BOOST FET GATE DRIVER CIRCUIT

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
VDRIVE UV detection threshold (Note 20)	VDRV_UV_[2]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 010]	54	58	62	%
VDRIVE UV detection threshold (Note 20)	VDRV_UV_[1]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 001]	46	50	54	%
VDRIVE UV detection threshold	VDRV_UV_[0]	Relative threshold to actual VDRIVE_VSETPOINT {VDRIVE_UV_THR = 000]		0		%
VDRIVE UV detection delay	VDRV_UV_DL		5		35	μs

18. The VDRIVE voltage drop between VDRIVE and VBB has to be sufficient (min. 0.5 V).
19. Both of these conditions have to be fulfilled otherwise SPI status bit VDRIVE_NOK is set.
20. Relative threshold to typical value of VDRIVE_VSETPOINT settings.

Table 8. VDD: 3 V LOW VOLTAGE ANALOG AND DIGITAL SUPPLY

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
VDD regulator output voltage	V_{DD}	Vbb > 5 V	3.135		3.465	V
DC output current consumption	VDD_IOUT	Vbb > 5 V, including 10 mA self current consumption			50	mA
Output current limitation	VDD_ILIM		60		350	mA

Table 9. POR: POWER−ON RESET CIRCUIT

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
POR Toggle level on VDD rising	POR3V_H		2.55		3.05	V
POR Toggle level on VDD falling	POR3V_L		2.3		2.8	V
POR Hysteresis	POR3V_HYST			0.15		V
POR threshold on VBB, VBB rising	POR_VBB_H	Applicable only during startup (VBB is rising)	3.8		4.3	V

Table 10. OTP MEMORY

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
Min. VBB for OTP zapping	VBB_OTP		15.8			V
VBB range for OTP_FAIL flag during OTP programming	VBB_OTP_L		13.2	14.1	15	V

Table 11. OSC10M: SYSTEM OSCILLATOR CLOCK

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
System oscillator frequency	FOSC10M		7	10	13	MHz

Table 12. BOOSTER (Note 21)

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
Booster overvoltage shutdown	BST_OV_127	[BOOST_OVERVOLTSD_THR =1111111], DC level	63.8	65.85	67.9	V
Booster overvoltage shutdown	BST_OV_022	[BOOST_OVERVOLTSD_THR =0010110], DC level	11	11.5	12	V
Booster overvoltage shutdown increase per code	ΔBST_OV	Linear increase, 7 bits		0.518	0.718	V

21. All parameters are guaranteed for recommended external Vboost resistor divider (Rdiv) ratio 34 with ±1% tolerance.
22. Higher levels are valid if BST_VLIMTH value 2 or 3 (BOOST_VLIMTHx[1] = 1) is selected at least on one channel.

Table 12. BOOSTER (Note 21)

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
Booster overvoltage re−activation	BST_RA_3	[BOOST_OV_REACT =11], ΔV to the Vboost reg. overvoltage protection, DC level	−1.9	−1.5	−1.1	V
Booster overvoltage re−activation	BST_RA_0	[BOOST_OV_REACT =00], ΔV to the Vboost reg. overvoltage protection, DC level		0		V
Booster overvoltage re−activation decrease per code	ΔBST_RA	Linear decrease, 2 bits, DC level	−0.6	−0.5		V
Booster undervoltage protection (external divider fail state detection)	BST_EA_UV		3.45	3.95	4.45	V
Booster undervoltage protection (external divider fail state detection) hysteresis	BST_EA_UV_HYST			0.6		V
Booster regulation level	BST_REG_125	[BOOST_VSETPOINT =1111101], DC level	62.8	64.8	66.8	V
Booster regulation level	BST_REG_022	[BOOST_VSETPOINT =0010110], DC level	11	11.5	12	V
Booster regulation level increase per code	ΔBST_REG	Linear increase, 7 bits		0.518	0.718	V
Transconductance gain of Error amplifier	BST_EA_GM3	[BOOST_OTA_GAIN =11], seen from VBOOST, DC value	63	90	117	μS
Transconductance gain of Error amplifier	BST_EA_GM2	[BOOST_OTA_GAIN =10], seen from VBOOST, DC value	42	60	78	μS
Transconductance gain of Error amplifier	BST_EA_GM1	[BOOST_OTA_GAIN =01], seen from VBOOST, DC value	21	30	39	μS
Transconductance gain of Error amplifier	BST_EA_GM0	[BOOST_OTA_GAIN =00], high impedance		0		μS
EA max output current	EA_IOUT_POS		150			μA
EA min output current	EA_IOUT_NEG				−150	μA
Output leakage current in tri−state	EA_ILEAK	Output in tri−state (EA_GM0)	−1		1	μA
EA output resistance	EA_ROUT			2.0		MΩ
EA max output voltage_3	COMP_CLH_3	BOOST_SLPCTRL[2]=1, OR of all BOOST_VLIMTHx[1]=1	2.1	2.26		V
EA max output voltage_2	COMP_CLH_2	BOOST_SLPCTRL[2]=1, OR of all BOOST_VLIMTHx[1]=0		1.98		V
EA max output voltage_1	COMP_CLH_1	BOOST_SLPCTRL[2]=0, OR of all BOOST_VLIMTHx[1]=1		1.64		V
EA max output voltage_0	COMP_CLH_0	BOOST_SLPCTRL[2]=0, OR of all BOOST_VLIMTHx[1]=0		1.35		V
EA min output voltage	COMP_CLL				0.4	V
Booster VOOSTDIV pin input pull up current	BST_EA_DIV_INI	Pull current source towards to VDD voltage	0.4	0.8	1.4	μA
Division of COMP on the Current comparator input	COMP_DIV_15	[P_DISTRIBUTIONx =01111], signed, see Power Distribution section and Table 19 for details		20		
Division of COMP on the current comparator input	COMP_DIV_0	[P_DISTRIBUTIONx =00000], signed, see Power Distribution section and Table 19 for details		6.81		
Division of COMP on the current comparator input	COMP_DIV_−16	[P_DISTRIBUTIONx =11111], signed, see Power Distribution section and Table 19 for details		4		

21. All parameters are guaranteed for recommended external Vboost resistor divider (Rdiv) ratio 34 with ±1% tolerance.
22. Higher levels are valid if BST_VLIMTH value 2 or 3 (BOOST_VLIMTHx[1] = 1) is selected at least on one channel.

Table 12. BOOSTER (Note 21)

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
Voltage shift on COMP on Current comparator input	COMP_VSF			+0.5		V
Booster skip cycle for low currents (Note 22)	BST_SKCL_3	[BOOST_SKCL =11], Booster disabled for lower V(COMP)		0.7/0.8		V
Booster skip cycle for low currents (Note 22)	BST_SKCL_2	[BOOST_SKCL =10], Booster disabled for lower V(COMP)		0.625/0.7		V
Booster skip cycle for low currents (Note 22)	BST_SKCL_1	[BOOST_SKCL =01], Booster disabled for lower V(COMP)		0.55/0.6		V
VGATE comparator to start BST_TOFF time	BST_VGATE_THR_1	[VBOOST_VGATE_THR = 1]		1.2		V
VGATE comparator to start BST_TOFF time	BST_VGATE_THR_0	[VBOOST_VGATE_THR = 0]		0.4		V
Booster minimum OFF time	BST_TOFF_7	[VBOOST_TOFF_SET = 111], time from VGATE below VBOOST_VGATE_THR	780	1200	1620	ns
Booster minimum OFF time	BST_TOFF_6	VBOOST_TOFF_SET = 110], time from VGATE below VBOOST_VGATE_THR	300	460	620	ns
Booster minimum OFF time	BST_TOFF_5	VBOOST_TOFF_SET = 101], time from VGATE below VBOOST_VGATE_THR	260	400	540	ns
Booster minimum OFF time	BST_TOFF_4	VBOOST_TOFF_SET = 100], time from VGATE below VBOOST_VGATE_THR	220	340	460	ns
Booster minimum OFF time	BST_TOFF_3	VBOOST_TOFF_SET = 011], time from VGATE below VBOOST_VGATE_THR	180	280	380	ns
Booster minimum OFF time	BST_TOFF_2	VBOOST_TOFF_SET = 010], time from VGATE below VBOOST_VGATE_THR	140	220	300	ns
Booster minimum OFF time	BST_TOFF_1	VBOOST_TOFF_SET = 001], time from VGATE below VBOOST_VGATE_THR	100	160	220	ns
Booster minimum OFF time	BST_TOFF_0	VBOOST_TOFF_SET = 000], time from VGATE below VBOOST_VGATE_THR	60	100	140	ns
Booster minimum ON time	BST_TON_7	[VBOOST_TON_SET =111], time from internal signal for VGATE drive	330	530	730	ns
Booster minimum ON time	BST_TON_6	[VBOOST_TON_SET =110], time from internal signal for VGATE drive	300	480	660	ns
Booster minimum ON time	BST_TON_5	[VBOOST_TON_SET =101], time from internal signal for VGATE drive	270	430	590	ns
Booster minimum ON time	BST_TON_4	[VBOOST_TON_SET =100], time from internal signal for VGATE drive	240	380	520	ns
Booster minimum ON time	BST_TON_3	[VBOOST_TON_SET =011], time from internal signal for VGATE drive	210	330	450	ns
Booster minimum ON time	BST_TON_2	[VBOOST_TON_SET =010], time from internal signal for VGATE drive	180	280	380	ns
Booster minimum ON time	BST_TON_1	[VBOOST_TON_SET =001], time from internal signal for VGATE drive	150	230	310	ns
Booster minimum ON time	BST_TON_0	[VBOOST_TON_SET =000], time from internal signal for VGATE drive	120	180	240	ns

21. All parameters are guaranteed for recommended external Vboost resistor divider (Rdiv) ratio 34 with ±1% tolerance.
22. Higher levels are valid if BST_VLIMTH value 2 or 3 (BOOST_VLIMTHx[1] = 1) is selected at least on one channel.

Table 13. BOOSTER – CURRENT REGULATION AND LIMITATION

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
Current comparator for Imax detection	BST_VLIMTHx_3	[BOOST_VLIMTHx =11], DC level of threshold voltage	95	100	105	mV
Current comparator for Imax detection	BST_VLIMTHx_2	[BOOST_VLIMTHx =10], DC level of threshold voltage	75	80	85	mV
Current comparator for Imax detection	BST_VLIMTHx_1	[BOOST_VLIMTHx =01], DC level of threshold voltage	57	62.5	67	mV
Current comparator for Imax detection	BST_VLIMTHx_0	[BOOST_VLIMTHx =00], DC level of threshold voltage	45	50	55	mV
Current comparator for Vboost regulation, offset voltage	BST_OFFS		−10		10	mV
Booster slope compensation	BST_SLPCTRL_7	BOOST_SLPCTRL =111], see Power Distribution section		290 / COMP_DIV		mV/ μs
Booster slope compensation	BST_SLPCTRL_6	BOOST_SLPCTRL =110], see Power Distribution section		190 / COMP_DIV		mV/ μs
Booster slope compensation	BST_SLPCTRL_5	BOOST_SLPCTRL =101], see Power Distribution section		120 / COMP_DIV		mV/ μs
Booster slope compensation	BST_SLPCTRL_4	BOOST_SLPCTRL =100], see Power Distribution section		85 / COMP_DIV		mV/ μs
Booster slope compensation	BST_SLPCTRL_3	BOOST_SLPCTRL =011], see Power Distribution section		50 / COMP_DIV		mV/ μs
Booster slope compensation	BST_SLPCTRL_2	BOOST_SLPCTRL =010], see Power Distribution section		35 / COMP_DIV		mV/ μs
Booster slope compensation	BST_SLPCTRL_1	BOOST_SLPCTRL =001], see Power Distribution section		17 / COMP_DIV		mV/ μs
Booster slope compensation	BST_SLPCTRL_0	BOOST_SLPCTRL =000], see Power Distribution section		0		mV/ μs
Sense voltage common mode range	CMVSENSE	Over full operating range	−0.1		1	V

Table 14. BOOSTER – PRE−DRIVER

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
High−side switch impedance	RONHI	t = 25°C		4.2		Ω
High−side switch impedance	RONHI	t = 150°C		6	7	Ω
Low−side switch impedance	RONLO	t = 25°C		4.2		Ω
Low−side switch impedance	RONLO	t = 150°C		6	7	Ω
Pull down resistor on VGATEx	RPDOWN			10		kΩ

Table 15. 5 V TOLERANT DIGITAL INPUTS (SCLK/TST2, CSB, SDI, BSTSYNC/TST/TST1, ENABLE1, FSO/ENABLE2, ENABLE3)

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
High−level input voltage	VINHI	SDI, BSTSYNC, CSB and SCLK/TST2	2			V
Low−level input voltage	VINLO	SDI, BSTSYNC, CSB and SCLK/TST2			0.8	V
Pull resistance (Note 23)	Rpull	SDI, BSTSYNC, CSB and SCLK/TST2	40		160	kΩ
High−level input voltage	ENA_VINHI	ENABLE1, FSO/ENABLE2, ENABLE3	2.35			V
Low−level input voltage	ENA_VINLO	ENABLE1, FSO/ENABLE2, ENABLE3			0.7	V
Pull resistance (Notes 23 and 24)	ENA_Rpull	ENABLE1, FSO/ENABLE2, ENABLE3	20		400	kΩ

23. Internal pull down resistor (Rpd) for SDI, ENABLE1, FSO/ENABLE2, ENABLE3, BSTSYNC and SCLK/TST2, pull up resistor (Rpu) for CSB to VDD.
24. VDD > POR3V_H; ENA_Rpull > 20 kΩ when VDD = 0 V to 3.5 V

Table 16. 5 V TOLERANT OPEN−DRAIN DIGITAL OUTPUT (SDO)

Characteristic	Symbol	Conditions	Min	Typ	Max	Unit
Low−voltage output voltage	VOUTLO	Iout = −10 mA (current flows into the pin)			0.4	V
Equivalent output resistance	RDSON	Lowside switch		20	40	Ω
SDO pin leakage current	SDO_ILEAK				2	μA
SDO pin capacitance (Note 25)	SDO_C				10	pF
CLK to SDO propagation delay	SDO_DL	Low−side switch activation/deactivation time; @1 kΩ to 5 V, 100 pF to GND, for falling edge V(SDO) goes below 0.5 V			60	ns

25. Guaranteed by bench measurement, not tested in production.

Table 17. SPI INTERFACE

Characteristic	Symbol	Min	Typ	Max	Unit
CSB setup time	t_{CSS}	0.5			μs
CSB hold time	t_{CSH}	0.25			μs
SCLK low time	t_{WL}	0.5			μs
SCLK high time	t_{WH}	0.5			μs
Data−in (DIN) setup time, valid data before rising edge of CLK	t_{SU}	0.25			μs
Data−in (DIN) hold time, hold data after rising edge of CLK	t_{H}	0.275			μs
Output (DOUT) disable time (Note 26)	t_{DIS}	0.07		0.32	μs
Output (DOUT) valid (Note 26)	$t_{V1\rightarrow0}$			0.32	μs
Output (DOUT) valid (Note 27)	$t_{V0\rightarrow1}$			0.32 + t(RC)	μs
Output (DOUT) hold time (Note 26)	t_{HO}	0.07			μs
CSB high time	t_{CS}	1			μs

26. SDO low−side switch activation time
27. Time depends on the SDO load and pull−up resistor

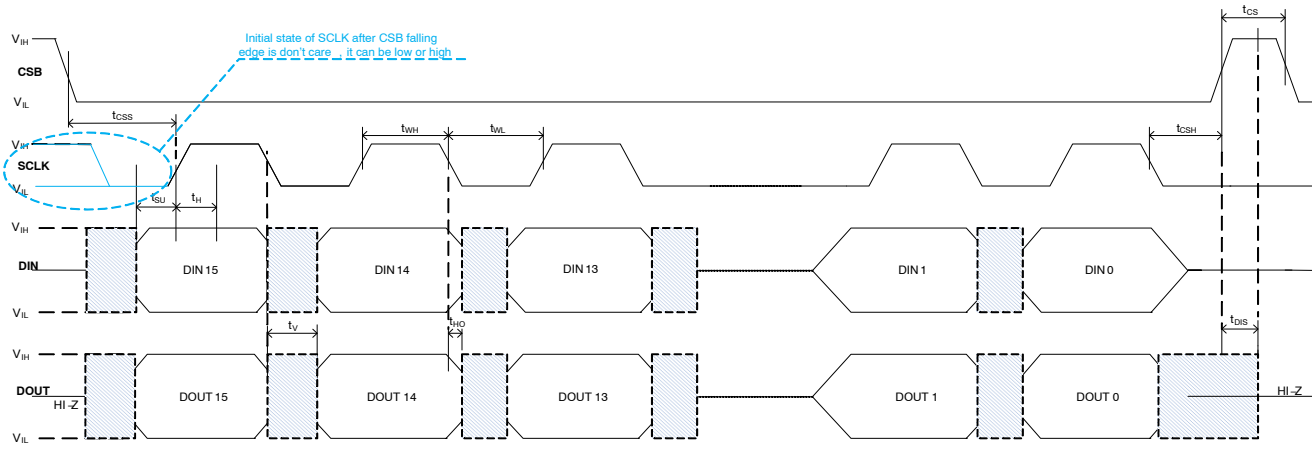


Figure 4. SPI Communication Timing

Typical Characteristics

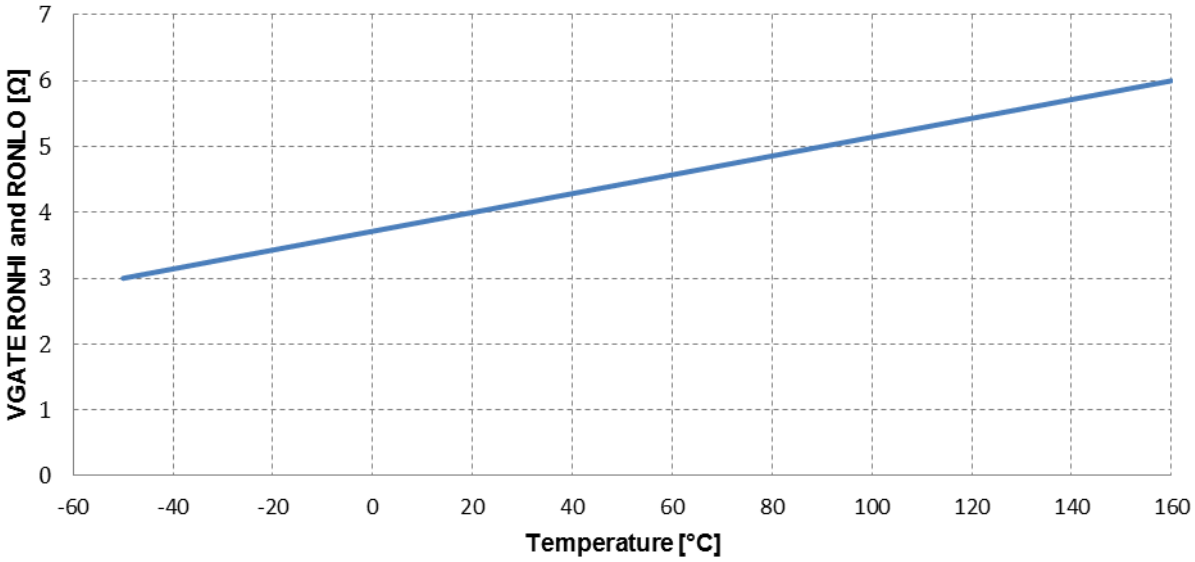


Figure 5. Typical temperature dependency of VGATE high and low side switch impedances

DETAILED OPERATING DESCRIPTION

Supply Concept in General

Low operating voltages become more and more required due to the growing use of start stop systems. In order to respond to this necessity, the NCV78703 is designed to support power−up starting from VBB = 5 V.

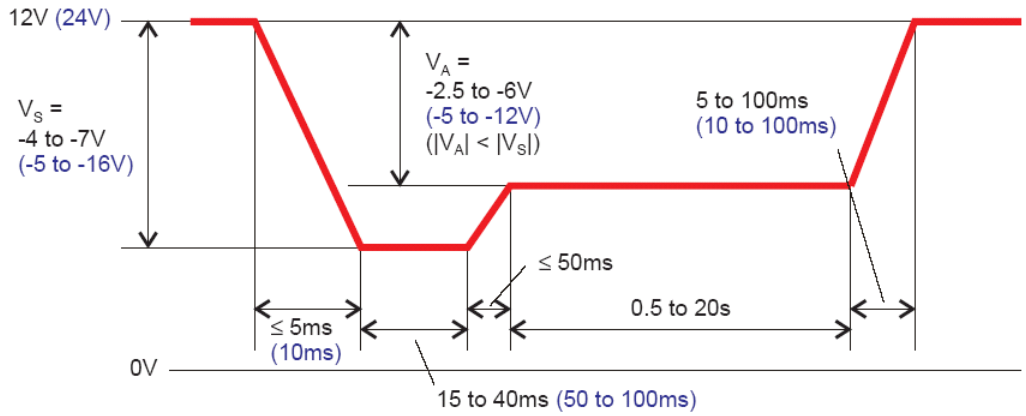


Figure 6. Cranking Pulse (ISO7637−1): System has to be fully functional (Grade A) from Vs = 5 V to 28 V

VDRIVE Supply

The VDRIVE supply voltage represents the power for the complete booster pre−driver block which generates the VGATE, used to switch the booster MOSFETs. The voltage is programmable via SPI in 16 different values (register VDRIVE_VSETPOINT[3:0], ranging from a minimum of 5 V typical to 10.1 V typical: see Table 7). This feature allows having the best switching losses vs. resistive losses trade off, according to the MOSFET selection in the application, also versus the minimum required battery voltage.

VDRIVE supply takes its energy from VBB battery voltage. Minimal VDRIVE regulator voltage drop is about 0.5 V. To ensure that booster can be operated close to minimal VBB battery voltage, logic level MOSFETs should be considered. By efficiency reasons, it is important to select MOSFETs with low gate charge. External MOSFETs are

controlled by the integrated pre−driver with slope control to reduce EMC emissions.

VDRIVE Undervoltage Lockout safety mechanism monitors sufficient voltage for MOSFETs and protects them by switching off the booster when VDRIVE voltage is too low. During initial 150 μs after POR the detection is disabled to ensure that normal operating mode is entered. Detection level is set by VDRIVE_UV_THR[2:0] register relatively to used VDRIVE voltage. Detection thresholds are summarized in Table 7. When VDRIVE_UV_THR[2:0] = 0, function is disabled.

VDD Supply

The VDD supply is the low voltage digital and analog supply for the chip and derives energy from VBB. Due to the low dropout regulator design, VDD is guaranteed already from low VBB voltages.

The Power−On−Reset circuit (POR) monitors the VDD and VBB voltages to control the out−of−reset condition at power−up. At least one ENABLE input is required to be in logic ‘1’ to enable the VDD regulator and leave reset state.

When SPI register VDD_ENA is set to ‘1’, VDD regulator stays enabled and chip stays in normal mode, even if all ENABLEx (x = 1, 2) inputs are set to logic ‘0’. When SPI register VDD_ENA is set to ‘0’ and all ENABLEx inputs are set to logic ‘0’, chip enters the reset state and VDD regulator is switched off.

VDD regulator is dimensioned to supply up to 8 NCV78713/NCV78723 buck devices.

Internal Clock Generation – OSC10M

An internal RC clock named OSC10M is used to run all the digital functions in the chip. The clock is trimmed in the factory prior to delivery. Its accuracy is guaranteed under full operating conditions and is independent from external component selection (refer to Table 11 for details). All timings depend on OSC10M accuracy.

Boost Regulator

General

The booster stage provides the required voltage source for the LED string voltages out of the available battery voltage. Moreover, it filters out the variations in the battery input current in case of LED strings PWM dimming.

For nominal loads, the boost controller will regulate in *continuous mode* of operation, thus maximizing the system power efficiency at the same time having the lowest possible input ripple current (with “continuous mode” it is meant that the supply current does not go to zero while the load is activated). Only in case of very low loads or low dimming duty cycle values, *discontinuous mode* can occur: this means the supply current can swing from zero when the load is off, to the required peak value when the load is on, while keeping the required input average current through the cycle. In such situations, the total efficiency ratio may be lower than the theoretical optimal. However, as also the total losses will at the same time be lower, there will be no impact on the thermal design.

On top of the using phases available in the device, the device can be combined with more NCV78702/NCV78703 devices in the application to gain even more phases. More details about the multichip−multiphase mode can be found in the dedicated section.

Booster Regulation Principles

The NCV78703 features a *current−mode* voltage boost controller, which regulates the VBOOST line used by the buck converters. The regulation loop principle is shown in the following picture. The loop compares the reference voltage (BOOST_VSETPOINT) with the actual measured voltage at the VBOOST pin, thus generating an error signal which is treated internally by the error trans−conductance amplifier (block A1). This amplifier transforms the error voltage into current by means of the trans−conductance gain Gm. The amplifier’s output current is then fed into the external compensation network impedance (A2), so that it originates a voltage at the VCOMP pin, this last used as a reference by the current control block (B).

The current controller regulates the duty cycle as a consequence of the VCOMP reference, the sensed inductor peak current via the external resistor R_{SENSE} and the slope compensation used. The power converter (block C) represents the circuit formed by the boost converter externals (inductor, capacitors, MOSFET and forward diode). The load power (usually the LED power going via the buck converters) is applied to the converter. The controlled variable is the boost voltage, measured directly at the device VBOOST pin with a unity gain feedback (block F). The picture highlights as block G all the elements contained inside the device. The regulation parameters are flexibly set by a series of SPI commands. A detailed internal boost controller block diagram is presented in the next section.

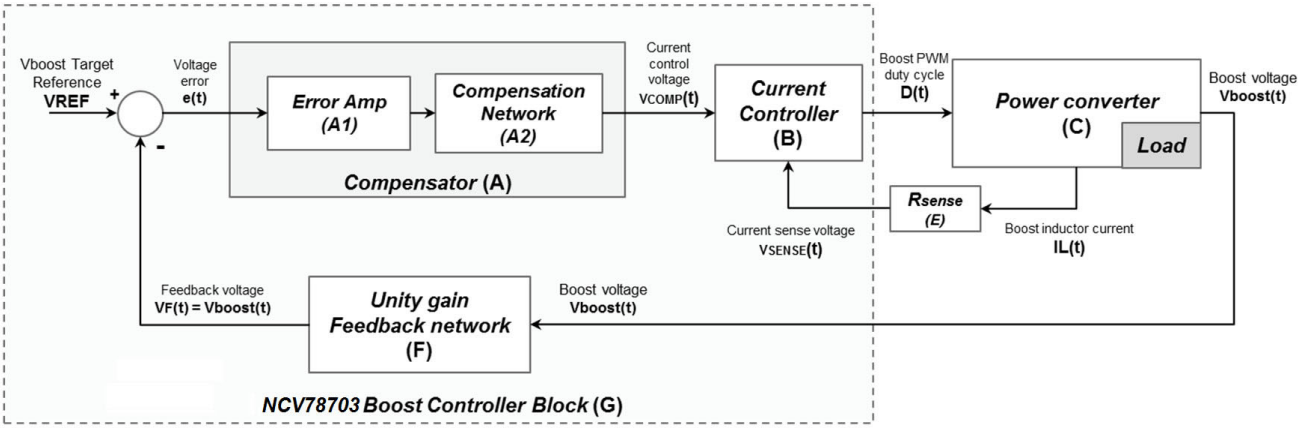


Figure 7. NCV78703 Boost Control Loop – Principle Block Diagram

Boost Controller Detailed Internal Block Diagram

A detailed NCV78703 boost controller block diagram is provided in this section. The main signals involved are indicated, with a particular highlight on the SPI programmable parameters.

The blocks referring to the principle block diagram are also indicated. In addition, the protection specific blocks can be found (see dedicated sections for details).

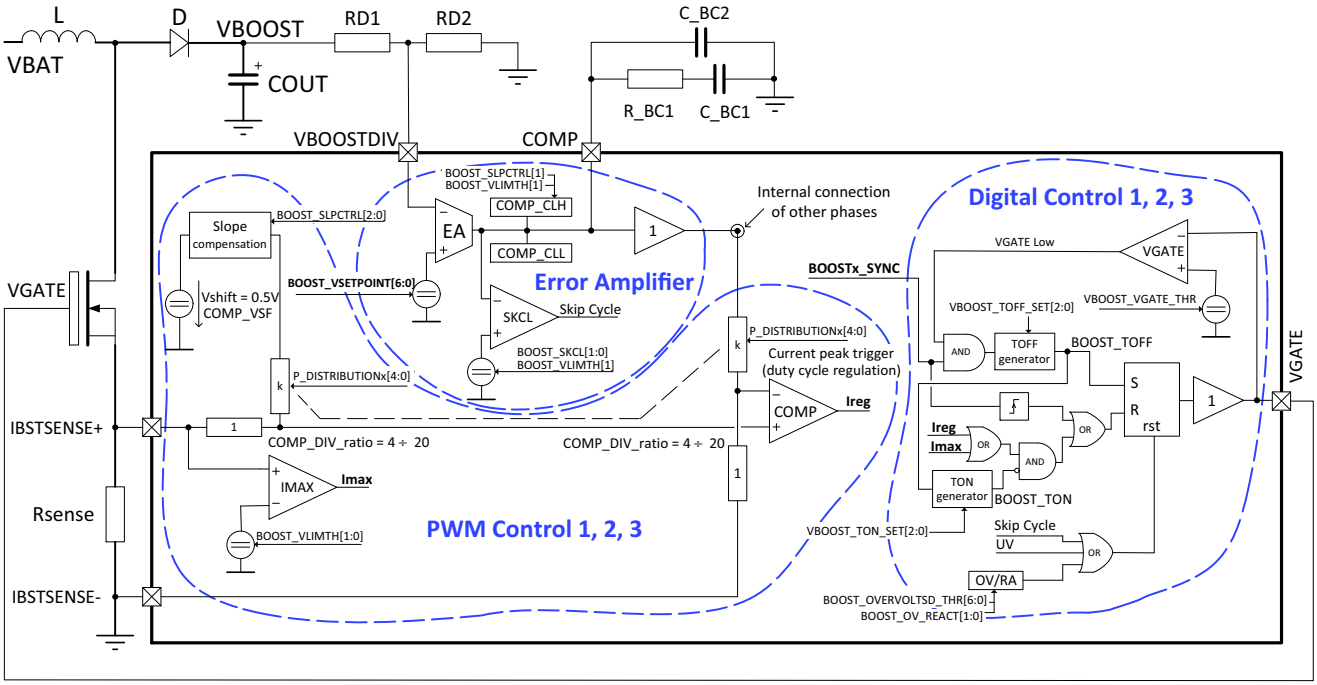


Figure 8. Boost Controller Internal Detailed Block Diagram

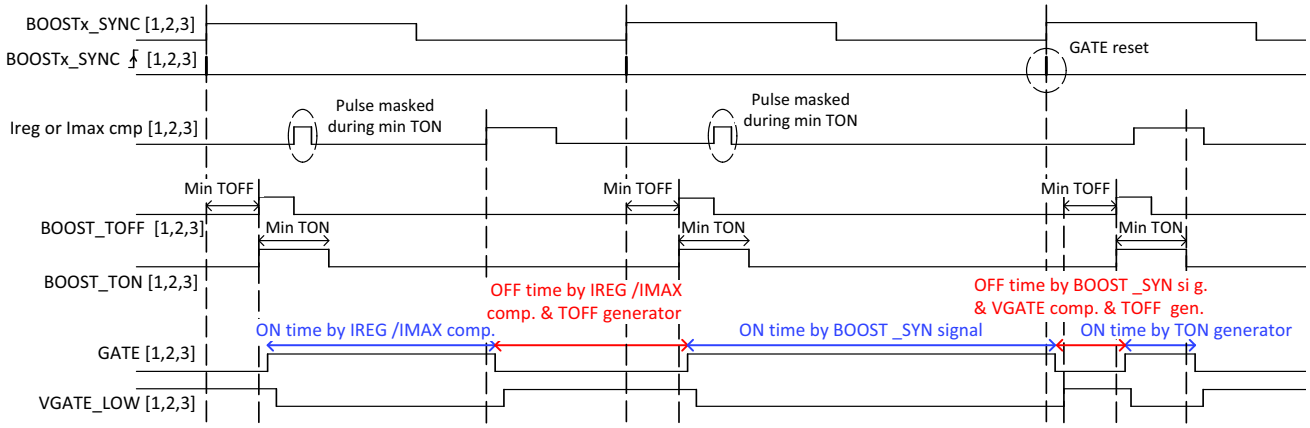


Figure 9. Boost Controller Internal Waveforms

Booster Regulator Setpoint (BOOST_VSETPOINT)

The booster voltage VBOOST is regulated around the target programmable by the 7−bit SPI setting BOOST_VSETPOINT[6:0], ranging from a minimum of 11.5 V to a maximum of typical 64.8 V (please refer to Table 12 for details). Due to the step−up only characteristic of any boost converter, the boost voltage cannot obviously be lower than the supply battery voltage provided. Therefore a target of 11.5 V would be used only for systems that require the activation of the booster in case of battery drops below the nominal level. At power−up, the booster is disabled and the setpoint is per default the minimum (all zeroes).

Booster Overvoltage Shutdown Protection

An integrated comparator monitors VBOOST in order to protect the external booster components from overvoltage. When the voltage rises above the threshold defined by the BOOST_OVERVOLTSD_THR[6:0], ranging from a minimum 11.5 V to a maximum of typical 65.85 V (please refer to Table 12 for details), the MOSFET gate is switched−off at least for the current PWM cycle and at the same time, the boost overvoltage flag in the status register will be set (BOOST_OV = '1'), together with the BOOSTx_STATUS flags equal to zero. The PWM runs again as from the moment the VBOOST will fall below the reactivation hysteresis defined by the BOOST_OV_REACT[1:0] SPI parameter. Therefore, depending on the voltage drop and the PWM frequency, it might be that more than one cycle will be skipped. A graphical interpretation of the protection levels is given in the figure below, followed by a summary table (Table 18).

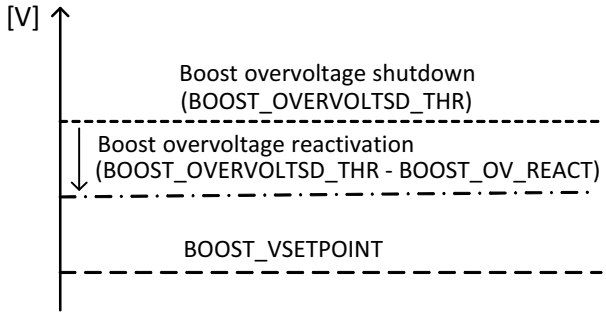


Figure 10. Booster voltage protection levels with respect to the setpoint

Table 18. BOOST OVERVOLTAGE PROTECTION LEVES AND RELATED DIAGNOSTIC

Case	Condition	PWM gate control	SPI flags	
			BOOSTx_STATUS	BOOST_OV
A	V_{BOOST} < BOOST_VSETPOINT	Normal (not disabled)	1	0
B	V_{BOOST} > BOOST_OVERVOLTSD_THR	Disabled until case 'C'	0	1 (latched)
C	V_{BOOST} < BOOST_OVERVOLTSD_THR − BOOST_OV_REACT	Re−enables the PWM, normal mode resumed if from case 'B'	1	1 (latched, if read in this condition, it will go back to '0'

Booster Current Regulation Loop

The peak−current level of the booster is set by the voltage of the compensation pin COMP, which is output of the trans−conductance error amplifier, “block B” of Figure 7. This reference voltage is fed to the current comparator via a divider (divider ratio of which can be set by Power sharing function for each phase independently, see “Power Distribution” section for more details. The comparator compares this reference voltage with voltage V_{SENSE} sensed on the external sense resistor R_{SENSE}, connected to the pins IBSTSENSE1/2/3+ and IBSTSENSE1/2/3−. The sense voltage is created by the booster inductor coil current when the MOSFET is switched on and is summed up to an additional offset of +0.5 V (see COMP_VSF in Table 12) and on top of that, a slope compensation voltage ramp is added. The slope compensation is programmable by SPI via the BOOST_SLPCTRL[2:0] register and can also be disabled. Due to the offset, current can start flowing in the circuit when V_{COMP} > COMP_VSF.

When booster is active, voltage at COMP pin is clamped to voltage between 0.4 V (see Table 12) and 1.35 V to 2.26 V depending on BOOST_VLIMTHx and BOOST_SLPCTRL settings (see Table 13) to ensure quicker reaction of the system to load changes.

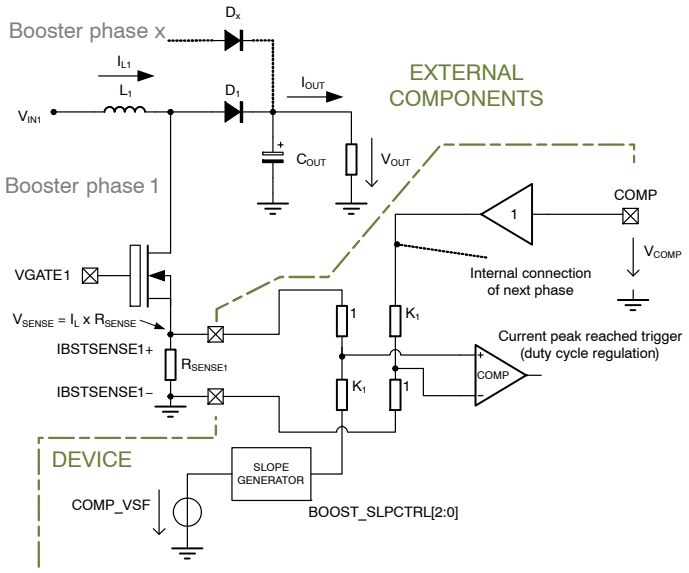


Figure 11. Booster Peak Current Regulator Involved in the Current Control Loop

Booster Current Limitation Protection

On top of the normal current regulation loop comparator, an additional comparator clamps the maximum physical current that can flow in the booster input circuit while the MOSFET is driven. The aim is to protect all the external components involved (boost inductor from saturation, boost diode and boost MOSFET from overcurrent, etc...). The protection is active PWM cycle−by−cycle and switches off the MOSFET gate when V_{SENSE} reaches its maximum threshold defined by the BOOST_VLIMTHx[1:0] register (see Table 13 for more details). Therefore, the maximum allowed peak current will be defined by the ratio I_{PEAK_MAX} = BOOST_VLIMTHx[1:0]/R_{SENSE}. The maximum current must be set in order to allow the total desired booster power for the lowest battery voltage. Warning: setting the current limit too low may generate unwanted system behavior as uncontrolled de−rating of the LED light due to insufficient power.

Booster PWM Internal Generation

Internally generated booster PWM signal is used only in FSO modes. When FSO mode is entered, booster PWM source is switched automatically from the external BSTSYNC pin to the internally generated signal, which is derived from the internal oscillator OSC10M. A selection of the frequencies is enabled by the register FSO_BST_FREQ[2:0], ranging from typical 200 kHz to typical 1 MHz (Table 22).

Booster PWM External Generation

In normal operation mode the booster PWM is taken directly from the BSTSYNC device pin. Maximum frequency at the BSTSYNC pin is 1 MHz. There is no actual limitation in the resolution, apart from the system clock for the sampling and a debounce of two clock cycles on the signal edges. The gate PWM is synchronized with either the rising or falling edge of the external signal depending on the BOOST_SRCINV bit value. The default POR value is “0” and corresponds to synchronization to the rising edge. BOOST_SRCINV equals “1” selects falling edge synchronization. Thanks to the possibility to invert external clock in the chip by SPI, up to 6−phase systems with shifted clock are supported with only 1 external clock.

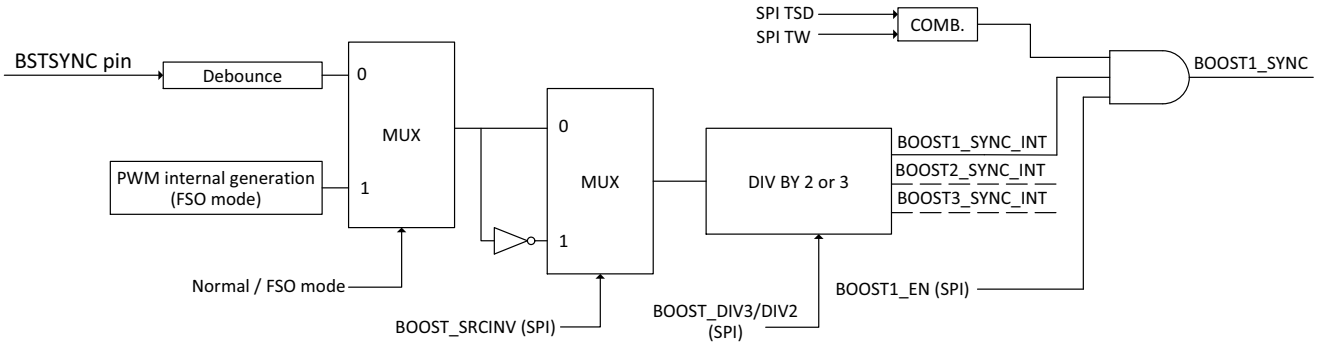


Figure 12. Generation of BOOSTx_SYNC

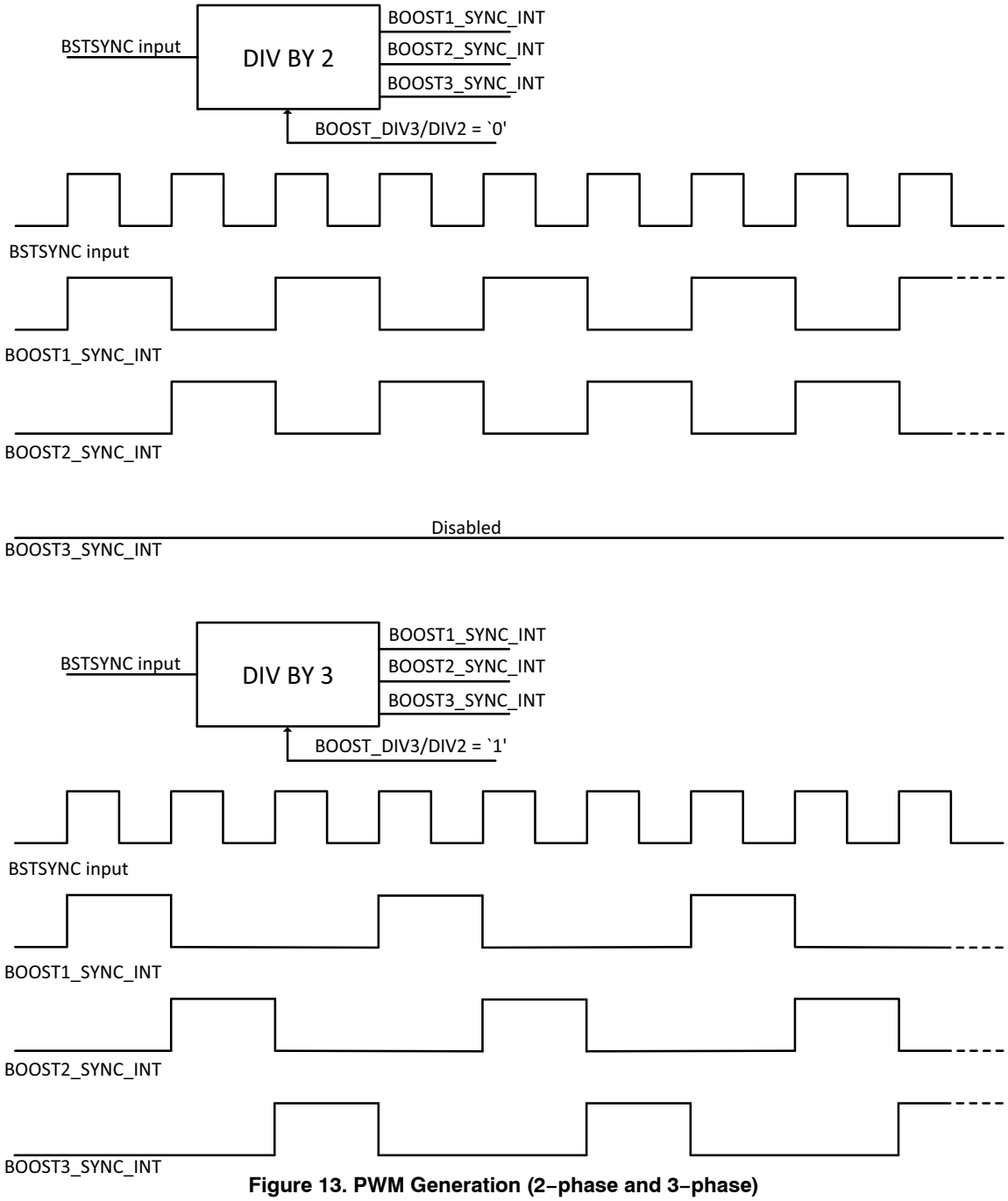


Figure 13. PWM Generation (2−phase and 3−phase)

Booster PWM Min TOFF and Min TON Protection

As additional protection, the PWM duty cycle is constrained between a minimum and a maximum, defined per means of two parameters available in the device.

The PWM *minimum on−time* is programmable via VBOOST_TON_SET[2:0]: its purpose is to guarantee a minimum activation interval for the booster MOSFET gate, to insure full drive of the component and avoiding switching in the linear region. Please note that this does not imply that the PWM is always running even when not required by the control loop, but means that whenever the MOSFET should be activated, then its on time would be at least the one specified. At the contrary when no duty cycle at all is required, then it will be zero.

The PWM *minimum off−time* is set via the parameter VBOOST_TOFF_SET[2:0]: this parameter is limiting the maximum duty cycle that can be used in the regulation loop for a defined period T_{PWM}:

$$Duty_{MAX} = \frac{(T_{PWM} - T_{OFFMIN})}{T_{PWM}}$$

The main aim of a maximum duty cycle is preventing MOSFET shoot−through in cases the (transient) duty cycle would get too close to 100% of the MOSFET real switch−off characteristics. In addition, as a secondary effect, a limit on the duty cycle may also be exploited to minimize the inrush current when the load is activated. Warning: a wrong setting of the duty cycle constraints may result in unwanted system behavior. In particular, a too big VBOOST_TOFF_SET[2:0] may prevent the system to regulate the VBOOST with low battery voltages (VBAT). This can be explained by the simplified formula for booster steady state continuous mode:

$$V_{BOOST} \cong \frac{V_{BAT}}{(1 - Duty)} \Leftrightarrow Duty \cong 1 - \frac{V_{BAT}}{V_{BOOST}}$$

So in order to reach a desired V_{BOOST} for a defined supply voltage, a certain duty cycle must be guaranteed.

Booster Compensator Model

A linear model of the booster controller compensator (block “A” Figure 7) is provided in this section. The protection mechanisms around are not taken into account. A type “2” network is taken into account at the VCOMP pin. The equivalent circuit is shown below:

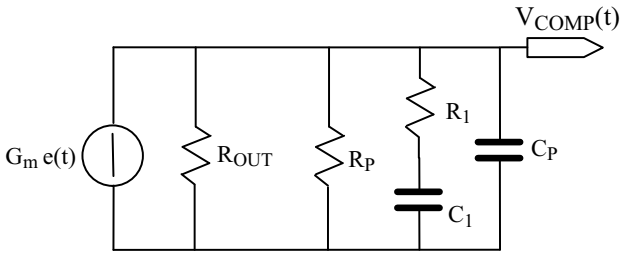


Figure 14. Booster Compensator Circuit with Type “2” Network

In the Figure, e(t) represents the control error, equals to the difference BOOST_VSETPOINT(t) − V_{BOOST}(t). “G_m” is the trans−conductance error amplifier gain, while “R_{OUT}” is the amplifier internal output resistance. The values of these two parameters can be found in Table 12 in this datasheet. By solving the circuit in Laplace domain the following error to V_{COMP} transfer function is obtained:

$$H_{COMP} = \frac{V_{COMP}(s)}{e(s)} = = G_m R_T \frac{\tau_1 s + 1}{\tau_1 \tau_P s^2 + (\tau_P + \tau_{1P})s + 1}$$

The explanation of the parameters stated in the equation above follows:

$$R_T = \frac{R_P \cdot R_{OUT}}{R_P + R_{OUT}}$$

$$\tau_1 = R_1 C_1$$

$$\tau_P = R_T C_P$$

$$\tau_{1P} = (R_1 + R_T) C_1$$

This transfer function model can be used for closed loop stability calculations.

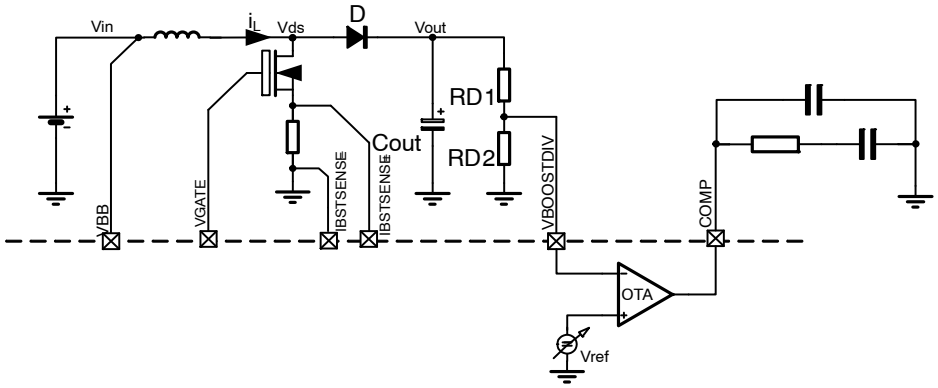


Figure 15. Voltage Divider and Compensation Network

Booster PWM Skip Cycles

In case of light booster load, it may be useful to reduce the number of effective PWM cycles in order to get a decrease of the input current inrush bursts and a less oscillating boost voltage. This can be obtained by using the “skip cycles” feature, programmable by SPI via BOOST_SKCL[1:0] (see Table 12 and SPI map). BOOST_SKCL[1:0] = ‘00’ means skip cycle disabled.

The selection defines the VCOMP voltage threshold below which the PWM is stopped, thus avoiding V_{BOOST} oscillations in a larger voltage window.

Booster Multiphase Mode Principles

The NCV78703 device supports three booster phases, which are connected together to the same VBOOST node, sharing the boost capacitor block. Multiphase mode shows to be a cost effective solution in case of mid to high power systems, where bigger external BOM components would be required to bear the total power in one phase only with the same performances and total board size. In particular, the boost inductor could become a critical item for very high power levels, to guarantee the required minimum saturation current and RMS heating current.

Another advantage is the benefit from EMC point of view, due to the reduction in ripple current per phase and ripple voltage on the module input capacitor and boost capacitor. The picture below shows the (very) ideal case of 50% duty cycle, the ripple of the total module current (I_{Lmp_sum} = I_{L1mp} + I_{L2mp}) is reduced to zero. The equivalent single phase current (I_{Lsp}) is provided as a graphical comparison.

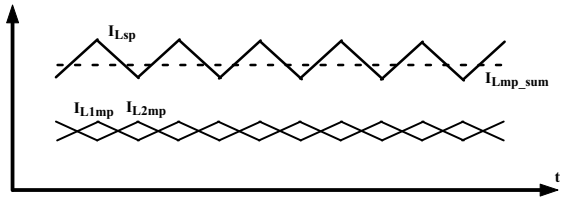


Figure 16. Booster Single Phase vs. Multiphase Example

Booster Multichip Connection Diagram and Programming

For high−power systems more NCV78702 and NCV78703 devices can be combined to gain even more synchronized booster phases.

This section describes the steps both from hardware and SPI programming point of view to operate in multichip mode. Example of physical connection of two devices is provided in this section. From a hardware point of view, it is assumed that in multiphase mode (N boosters), each stage has the same external components. The following features have to be considered as well:

1. The compensation pin (COMP) of all boosters is connected together to the same compensation network, to equalize the power distribution of each booster (booster phases work with the equal peak current). For the best noise rejection, the compensation network area has to be surrounded by the GND plane.
2. Boosters are synchronized by using shared external clock, generated by MCU or external logic, according to the user−defined control strategy. The generic number of lines needed is equivalent to the number of devices. When two chips are combined, the slave device shall have BOOST_SRCINV bit at ‘1’ (clock polarity internal inversion active), whereas the master device will keep the BOOST_SRCINV bit at ‘0’ (= no inversion, default).
3. Only the master device’s error amplifier OTA must be active, while the other (slave) devices must have all their own OTA blocks disabled (BOOST_OTA_GAIN[1:0] = ‘00’). Master device should have the register BOOST_MULTI_PHASE_MD[1:0] set to ‘01’ (Multiphase Mode − MASTER), this will ensure that Error Amplifier of this device drives COMP signal which is shared between all devices. Other (slave) devices should have BOOST_MULTI_PHASE_MD[1:0] set to ‘10’ (Multiphase Mode − SLAVE), meaning that COMP pin is used only to sense the voltage.
4. Overvoltage settings of master and slave devices should be set to the same level. Each device senses boost voltage via VBOOSTDIV pin and reacts to the overvoltage situation independently. See also “Booster overvoltage shutdown protection” for more details on the protection mechanism and threshold.

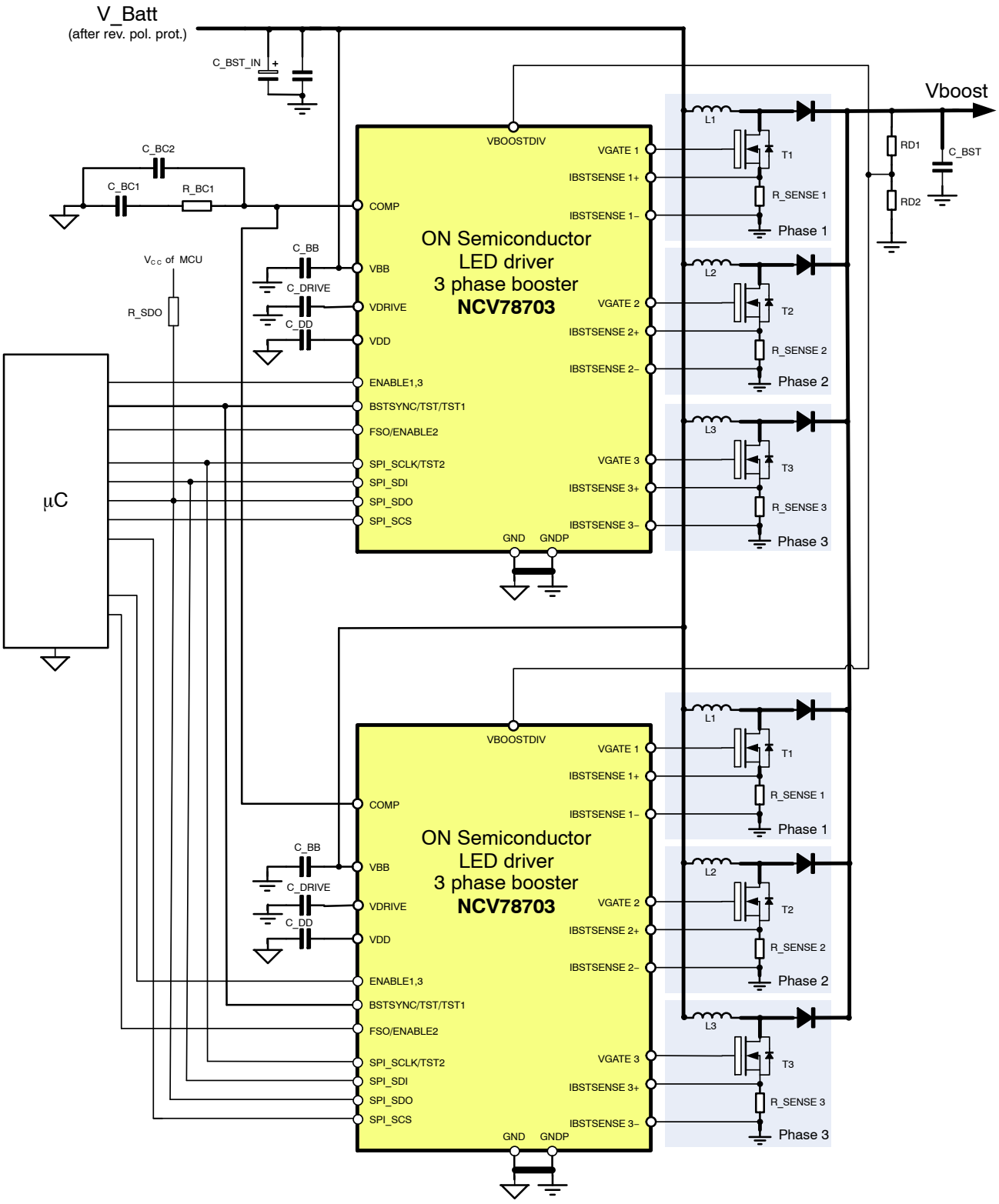


Figure 17. Booster Multichip Connection Example

Booster Enable and Disable Control

By means of FSO_ENABLE_SEL SPI registers, function of FSO/ENABLE2 pin can be selected.

When FSO_ENABLE_SEL = ‘0’, FSO function is enabled (FSO mode can be entered by falling edge on this pin). In this case each phase of the booster can be enabled/disabled by corresponding BOOSTx_EN bit. The enable signal is the transition from ‘0’ to ‘1’, the disable function is vice−versa.

When FSO_ENABLE_SEL = ‘1’, ENABLE function is enabled (independent control of booster phases). When the independent control of the phases is chosen, a booster x is activated only when SPI bit BOOSTx_EN is ‘1’ and corresponding debounced ENABLEx pin is in logic ‘1’.

When BOOSTx_EN = ‘0’, the corresponding channel is off and its GATE drive is disabled. Please note that even when all phases are off, the error amplifier is not shut off automatically and to avoid voltage generation on the VCOMP pin the G_m gain must be put to zero as well.

Power Distribution

Current peak regulation level I_{PEAK} in current regulation loop can be modified by changing of division ratio of the internal voltage divider in range from 4 to 20 (see COMP_DIV parameter in Table 12 and Table 19) for each phase individually by SPI registers P_DISTRIBUTIONx[4:0].

The same internal divider is also in path of slope compensation, internal slope has to be translated into corresponding slope on sensing resistor R_{SENSE} according to Table 13 and Table 19.

Power distribution feature allows setting of the ratio between peak values of the currents in the individual booster channels. This can serve to:

- balance power sharing between booster phases which can differ because of external components tolerances and device specification;
- set different power levels to the individual phases without changing external components (R_{SENSE}).

Because peak value of the current I_{PEAK} is modified by power distribution setting, the average current $I_{AVERAGE}$ and corresponding power P have to be computed by the following formulas when operated in continuous mode:

$I_{AVERAGE} = I_{PEAK} – I_{RIPPLE}/2$, $P = I_{AVERAGE} \cdot V_{BAT}$.

Individual intermediate values of COMP_DIV are computed according to the following equation:

$$COMP\_DIV = \frac{1}{\frac{1}{20} + \frac{15 - P\_DISTRIBUTION[4:0](signed)}{155}}$$

Table 19. POWER DISTRIBUTION

P_DISTRIBUTIONx[4:0] unsigned		31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
P_DISTRIBUTIONx[4:0] signed		-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1
COMP_DIV_ratio		4.00	4.11	4.22	4.34	4.46	4.59	4.73	4.88	5.04	5.21	5.39	5.59	5.79	6.02	6.26	6.53
	Internal slope [mV/us]																
Slope_Comp_0 (mV/us @ Rsense)	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slope_Comp_1 (mV/us @ Rsense)	17	4.25	4.14	4.03	3.92	3.81	3.70	3.59	3.48	3.37	3.26	3.15	3.04	2.94	2.82	2.72	2.60
Slope_Comp_2 (mV/us @ Rsense)	35	8.75	8.52	8.29	8.06	7.85	7.63	7.40	7.17	6.94	6.72	6.49	6.26	6.04	5.81	5.59	5.36
Slope_Comp_3 (mV/us @ Rsense)	50	12.50	12.17	11.85	11.52	11.21	10.89	10.57	10.25	9.92	9.60	9.28	8.94	8.64	8.31	7.99	7.66
Slope_Comp_4 (mV/us @ Rsense)	85	21.25	20.68	20.14	19.59	19.06	18.52	17.97	17.42	16.87	16.31	15.77	15.21	14.68	14.12	13.58	13.02
Slope_Comp_5 (mV/us @ Rsense)	120	30.00	29.20	28.44	27.65	26.91	26.14	25.37	24.59	23.81	23.03	22.26	21.47	20.73	19.93	19.17	18.38
Slope_Comp_6 (mV/us @ Rsense)	190	47.50	46.23	45.02	43.78	42.60	41.39	40.17	38.93	37.70	36.47	35.25	33.99	32.82	31.56	30.35	29.10
Slope_Comp_7 (mV/us @ Rsense)	290	72.50	70.56	68.72	66.82	65.02	63.18	61.31	59.43	57.54	55.66	53.80	51.88	50.09	48.17	46.33	44.41

P_DISTRIBUTIONx[4:0] unsigned		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P_DISTRIBUTIONx[4:0] signed		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
COMP_DIV_ratio		6.81	7.13	7.47	7.85	8.27	8.73	9.25	9.84	10.51	11.27	12.16	13.19	14.42	15.90	17.71	20.00
	Internal slope [mV/us]																
Slope_Comp_0 (mV/us @ Rsense)	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slope_Comp_1 (mV/us @ Rsense)	17	2.50	2.38	2.28	2.17	2.06	1.95	1.84	1.73	1.62	1.51	1.40	1.29	1.18	1.07	0.96	0.85
Slope_Comp_2 (mV/us @ Rsense)	35	5.14	4.91	4.69	4.46	4.23	4.01	3.78	3.56	3.33	3.11	2.88	2.65	2.43	2.20	1.98	1.75
Slope_Comp_3 (mV/us @ Rsense)	50	7.34	7.01	6.69	6.37	6.05	5.73	5.41	5.08	4.76	4.44	4.11	3.79	3.47	3.14	2.82	2.50
Slope_Comp_4 (mV/us @ Rsense)	85	12.48	11.92	11.38	10.83	10.28	9.74	9.19	8.64	8.09	7.54	6.99	6.44	5.89	5.35	4.80	4.25
Slope_Comp_5 (mV/us @ Rsense)	120	17.62	16.83	16.06	15.29	14.51	13.75	12.97	12.20	11.42	10.65	9.87	9.10	8.32	7.55	6.78	6.00
Slope_Comp_6 (mV/us @ Rsense)	190	27.90	26.65	25.44	24.20	22.97	21.76	20.54	19.31	18.08	16.86	15.63	14.40	13.18	11.95	10.73	9.50
Slope_Comp_7 (mV/us @ Rsense)	290	42.58	40.67	38.82	36.94	35.07	33.22	31.35	29.47	27.59	25.73	23.85	21.99	20.11	18.24	16.37	14.50

Diagnostics

The NCV78703 features a wide range of embedded diagnostic features. Their description follows.

Diagnostic Description

- **Thermal Warning:** this mechanism detects a junction temperature which is in principle close, but lower, to the chip maximum allowed, thus providing the information that some action (power de−rating) is required to prevent overheating that would cause Thermal Shutdown. The thermal warning flag (TW) is given in status register 0x0A and is latched. Thermal warning threshold is typically 160°C (see Table 6).
- **Thermal Shutdown:** this safety mechanism intends to protect the device from damage caused by overheating, by disabling the booster channels. The diagnostic is displayed per means of the TSD bit in status register 0x0A (latched). Once occurred, the thermal shutdown condition is exited when the temperature drops below the thermal warning level, thus providing hysteresis for thermal shutdown recovery process. Booster channels are re−enabled automatically if TSD_AUT_RCVR_EN = 1, respectively can be re−enabled by rising edge on BOOSTx_EN if TSD_AUT_RCVR_EN = 0. The application thermal design should be made as such to avoid the thermal shutdown in the worst case conditions. The thermal shutdown level is not user programmable and is factory trimmed to typically 170°C (see Table 6).
- **Temperature output:** allows to observe temperature of the chip by the means of the adjustable threshold ADC_TEMP_THR[2:0] (see Table 6). When temperature exceeds the threshold, status flag TEMP_OUT is set.
- **SPI Error:** in case of SPI communication errors the SPIERR bit in status register 0x0A is set. The bit is latched. For more details, please refer to section “SPI protocol: framing and parity error”.
- **HW reset:** the out of reset condition is reported through the HWR bit (latched). This bit is set only at each Power On Reset (POR) and indicates the device is ready to operate.
- **Booster Overvoltage Shutdown:** Whenever the boost overvoltage detection triggers in the control loop, the BOOST_OV flag (latched, register 0x0A) is set and booster is switched off. The booster is automatically activated when voltage falls below the hysteresis defined by Booster overvoltage re−activation parameter in Table 12.
- **Booster Undervoltage Protection:** when voltage at booster divider pin VBOOSTDIV drops below BST_EA_UV level (see Table 12) because of external divider failure, the VBSTDIV_UV flag (latched, 0x0B) is displayed and booster is switched off to protect external components from the overvoltage.
- **VDRIVE Out of Regulation:** correct work of VDRIVE regulator is monitored by checking VBB – VDRIVE voltage difference which has to be at least 0.5 V and by checking current drawn from the regulator. If one or both conditions are not met, VDRIVE_NOK flag is displayed (latched, 0x0B).
- **VDRIVE Undervoltage Lockout:** this safety mechanism monitors sufficient voltage for MOSFETs and protects them by switching off the booster when VDRIVE voltage is too low. During initial 150 μs after POR the detection is disabled to ensure that normal operating mode is entered. Detection level is set by VDRIVE_UV_THR[2:0] register relatively to used VDRIVE voltage (set by VDRIVE_VSETPOINT[3:0] register). Detection thresholds are summarized in Table 7. When VDRIVE_UV_THR[2:0] = 0, function is disabled.
- **Booster status:** the physical activation of the booster phase is displayed by the BOOSTx_STATUS flag (non−latched, 0x0A). Please note this is different from the BOOSTx_EN control bit, which reports instead the *willing* to activate the booster. See also section ”Booster Enable Control”.
- **Enable pin status:** the actual logic status read at ENABLEx pin is reported by the flag ENABLEx_STATUS (non−latched, 0x0B). Thanks to this diagnostic, the MCU can check proper logic level on the pin.

A short summary table of the main diagnostic bits related to the LED outputs follows.

Table 20. DIAGNOSTIC SUMMARY

Diagnose		Detection level	Booster Output	Latched
Flag	**Description**			
TW	Thermal Warning	Factory trimmed	No change	Yes
TSD	Thermal Shutdown	Factory trimmed	Disabled. Re−enabled by rising edge on BOOSTx_EN after Tj < TW and TSD flag was cleared. Re−enabled automatically when TSD_AUT_RCVR_EN bit is set (in FSO/SA modes always).	Yes
TEMP_OUT	Temperature Output	See Diagnostic section	No change	Yes
SPIERR	SPI error	See SPI section	No change	Yes
BOOST_OV	Overvoltage Shutdown	See Electrical Characteristics	Disabled. Re−enabled automatically below BOOST_RA threshold.	Yes
VBSTDIV_UV	Undervoltage Protection	See Electrical Characteristics	Disabled. Re−enabled by rising edge on BOOSTx_EN when VBOOSTDIV > BST_EA_UV	Yes
VDRIVE_NOK	VDRIVE Out of regulation	See Electrical Characteristics	No change	Yes
VDRIVE_UV *	VDRIVE UV Lockout	See Diagnostic section. Depends on SPI VDRIVE_VSETPOINT[3:0] and VDRIVE_UV_THR[2:0] settings.	Disabled. Re−enabled by rising edge on BOOSTx_EN after VDRIVE_UV condition disappears.	Yes
HWR	HW Reset	Set after POR	No change	Yes

*The flag not available in SPI map

Table 21. TSD RECOVERY OVERVIEW

FSO_ENABLE_SEL SPI bit	TSD_AUT_RCVR_EN SPI bit	ENABLEx pin	BOOSTx_EN SPI bit	BOOSTERx status after TSD disappear
0	**0**	**x**	**0**	**Disabled**
0	**0**	**x**	**1**	**Disabled**
0	**0**	**x**	**0 → 1**	**Enabled**
0	**1**	**x**	**0**	**Disabled**
0	**1**	**x**	**1**	**Enabled**
1	**0**	**0**	**0**	**Disabled**
1	**0**	**0**	**1**	**Disabled**
1	**0**	**1**	**0**	**Disabled**
1	**0**	**1**	**1**	**Disabled**
1	**0**	**0 → 1**	**1**	**Disabled**
1	**0**	**1**	**0 → 1**	**Enabled**
1	**1**	**0**	**0**	**Disabled**
1	**1**	**0**	**1**	**Disabled**
1	**1**	**1**	**0**	**Disabled**
1	**1**	**1**	**1**	**Enabled**

NOTE: 0 → 1 … rising edge (after TW disappeared)

Functional Mode Description

Reset

POR always causes asynchronous reset − transition to reset state. The Power−On−Reset circuit (POR) monitors the VDD and VBB voltages to control the out−of−reset condition at power−up. Chip will leave the reset state and VDD regulator will be enabled when VBB > POR_VBB_H and VDD > POR3V_H and at least one ENABLE input is in logic ‘1’.

When SPI register VDD_ENA is set to ‘1’, VDD regulator stays enabled and chip stays in normal mode, even if all ENABLE inputs are set to logic ‘0’. When SPI register VDD_ENA is set to ‘0’ and all ENABLE inputs are set to logic ‘0’, chip enters the reset state and VDD regulator is switched off, current consumption from VBB is less than 1 μA (for T_J = 30°C).

Init and Normal mode

Normal mode is entered through Init state after internal delay of 150 μs. In Init state, OTP refresh is performed. If OTP bits for FSO_MD[2:0] register and *OTP Lock Bit* are programmed, transition to FSO/SA mode is possible.

Device is fully started 500 μs after rising edge on ENABLE pin.

FSO/Stand−Alone mode

FSO (Fail−Safe Operation)/Stand−Alone modes can be used for two main purposes:

- Default power−up operation of the chip (**Stand−Alone** functionality without external microcontroller or preloading of the registers with default content for default operation before microcontroller starts sending SPI commands for chip settings)
- **Fail−Safe** functionality (chip functionality definition in fail−safe mode when the external microcontroller functionality is not guaranteed)

FSO/stand−alone function is controlled according to Table 24. Entrance into FSO/Stand−alone mode is possible only after costumer OTP zapping when *OTP Lock Bit* is set.

FSO/ENABLE2 pin serves to enter/exit FSO mode when SPI bit FSO_ENABLE_SEL = “0” (meaning that function of the pin is “FSO”). If FSO_ENABLE_SEL = “1”, FSO mode cannot be entered. Independent control of booster phases (FSO_ENABLE_SEL = ‘1’) is not available in FSO mode. When FSO_ENABLE_SEL is changed in FSO mode from ‘0’ to ‘1’, the FSO mode is immediately exited.

Actual value of SPI register FSO_MD[2:0] (preloaded from OTP only at power−up) is used for entrance into FSO mode and all FSO related functions are then controlled according to it.

When FSO mode is entered, SPI status bit FSO is set. It is clear by read flag.

When FSO/Stand−Alone mode is activated, content of the following SPI registers is preloaded from OTP memory:

BOOST_SKCL[1:0]
BOOST_OTA_GAIN[1:0]
VDRIVE_VSETPOINT[3:0]
VBOOST_VGATE_THR
BOOST_VLIMTH1[1:0]
BOOST_VLIMTH2[1:0]
BOOST_OV_REACT[1:0]
BOOST_SLPCTRL[2:0]
BOOST_OVERVOLTSD_THR[6:0]
BOOST_SRCINV
BOOST_MULTI_PHASE_MD[1:0]
BOOST_VSETPOINT[6:0]
FSO_BST_FREQ[2:0]
BOOST1_EN
BOOST2_EN
VDD_ENA
FSO_ENABLE_SEL
VBOOST_TOFF_SET[2:0]
VBOOST_TON_SET[2:0]
P_DISTRIBUTION1[4:0]
P_DISTRIBUTION2[4:0]
VDRIVE_UV_THR[2:0]

In FSO (entered via falling edge on FSO/ENABLE2 pin) or Stand−Alone modes, internal booster PWM source with 50% duty cycle is used as booster frequency. Frequency at which booster runs is determined by value in FSO_BST_FREQ[2:0] register. Values which can be selected are shown in the following table.

Table 22. BOOSTER FREQUENCY IN FSO MODES

FSO_BST_FREQ[2:0]	Booster freq. [kHz]
0x0	200
0x1	294.1
0x2	416.7
0x3	500
0x4	625
0x5	714.3
0x6	833
0x7	1000

TSD_AUT_RCVR_EN is kept high ‘1’ in FSO or Stand−Alone modes, allowing automatic recovery when thermal shutdown occurs. TSD_AUT_RCVR_EN is loaded from OTP only when FSO_MD[2:0] = 1.

BOOSTx_EN bits are kept high ‘1’ in FSO modes (entered via falling edge on FSO pin), enabling booster phases. If BOOSTx_EN values preloaded from OTP’s are and remain ‘0’, corresponding booster phases will be disabled when FSO mode is exited.

Table 23. FSO MODES OVERVIEW

FSO_MD[2:0]	FSO entered after startup	FSO entered after falling edge on FSO pin	SPI ctrl. registers loaded with "00" after POR	SPI ctrl. registers loaded with values from customer OTPs after POR	SPI registers update in FSO enabled	OTP programming needed
0	N	N	Y	N	N	N
1	N	N	N	Y	N	Y
2	N	Y	Y	N	N	Y
3	N	Y	Y	N	Y	Y
4	N	Y	N	Y	N	Y
5	N	Y	N	Y	Y	Y
6	Y	N	N	Y	N	Y
7	Y	Y*	N	Y	Y	Y

*after proper FSO_MD[2:0] register update

Table 24. FSO MODES DESCRIPTION

FSO_MD[2:0]	Description
000_b = 0	**FSO mode disabled, registers are loaded with safe value = 0x00h after POR, default** • After the reset, control registers are loaded with 0x00h value. • Entrance into FSO mode is not possible
001_b = 1	**FSO mode disabled, registers are loaded with data from OTP memory after POR** • After the reset, control registers are loaded with data stored in OTP memory (device's OTP memory has to be programmed, *OTP Lock Bit* has to be set). It reduces number of SPI transfers needed to configure the device after the reset. • Entrance into FSO mode is not possible
010_b = 2	**FSO entered after falling edge on FSO pin, registers are loaded with safe value = 0x00h after POR** • After FSO mode activation, control registers are loaded with data stored in OTP memory. • SPI register update (SPI write/read operation) in FSO mode is **disabled** (SPI write operation is blocked; clearing of SPI registers is blocked; SPIERR flag is set in case of invalid SPI frame). • FSO/ENABLE2 pin serves to enter/exit FSO mode (when SPI bit FSO_ENABLE_SEL = 0). • Internal booster PWM source will be selected as the booster frequency after activation of FSO mode.
011_b = 3	**FSO entered after falling edge on FSO pin, registers are loaded with safe value = 0x00h after POR** • After FSO mode activation, control registers are loaded with data stored in OTP memory. • SPI register update (SPI write/read operation) in FSO mode is **enabled** • FSO mode can be exited by writing FSO_MD[2:0] = 000 or 001 • FSO/ENABLE2 pin serves to enter/exit FSO mode (when SPI bit FSO_ENABLE_SEL = 0). • If SPI bit FSO_ENABLE_SEL is written with '1' in FSO mode, the FSO mode is immediately exited. • Internal booster PWM source will be selected as the booster frequency after activation of FSO mode.
100_b = 4	**FSO entered after falling edge on FSO pin, registers are loaded with data from OTP memory after POR** • After FSO mode activation, control registers are loaded with data stored in OTP memory. • SPI register update (SPI write/read operation) in FSO mode is **disabled** (SPI write operation is blocked; clearing of SPI registers is blocked; SPIERR flag is set in case of invalid SPI frame). • FSO/ENABLE2 pin serves to enter/exit FSO mode (when SPI bit FSO_ENABLE_SEL = 0). • Internal booster PWM source will be selected as the booster frequency after activation of FSO mode.
101_b = 5	**FSO entered after falling edge on FSO pin, registers are loaded with data from OTP memory after POR** • After FSO mode activation, control registers are loaded with data stored in OTP memory. • SPI register update (SPI write/read operation) in FSO mode is **enabled** • FSO mode can be exited by writing FSO_MD[2:0] = 000 or 001 • FSO/ENABLE2 pin serves to enter/exit FSO mode (when SPI bit FSO_ENABLE_SEL = 0). • If SPI bit FSO_ENABLE_SEL is written with '1' in FSO mode, the FSO mode is immediately exited. • Internal booster PWM source will be selected as the booster frequency after activation of FSO mode.
110_b = 6	**SA (stand−alone)/FSO entered after POR, registers are loaded with data from OTP memory** • After SA/FSO mode activation, control registers are loaded with data from OTP memory • SPI register update (SPI write/read operation) in SA/FSO mode is **disabled** (SPI write operation is blocked; clearing of SPI registers is blocked; SPIERR flag is set in case of invalid SPI frame). • Internal booster PWM source will be selected as the booster frequency.
111_b = 7	**SA (stand−alone)/FSO entered after POR, registers are loaded with data from OTP memory** • After SA/FSO mode activation, control registers are loaded with data from OTP memory • SPI register update (SPI write/read operation) in SA/FSO mode is **enabled** • FSO mode can be exited by writing FSO_MD[2:0] = 000 or 001 • If SPI bit FSO_ENABLE_SEL is written with '1' in FSO mode, the FSO mode is immediately exited. • Internal booster PWM source will be selected as the booster frequency.

SPI Interface

General

The serial peripheral interface (SPI) is used to allow an external microcontroller (MCU) to communicate with the device. NCV78703 acts always as a slave and it cannot initiate any transmission. The operation of the device is configured and controlled by means of SPI registers, which are observable for read and/or write from the master. The NCV78703 SPI transfer size is 16 bits.

During an SPI transfer, the data is simultaneously transmitted (shifted out serially) and received (shifted in serially). A serial clock line (SCLK) synchronizes shifting and sampling of the information on the two serial data lines: SDO and SDI. The SDO signal is the output from the Slave (NCV78703), and the SDI signal is the output from the Master.

A slave or chip select line (CSB) allows individual selection of a slave SPI device in a time multiplexed multiple−slave system.

The CSB line is active low. If an NCV78703 is not selected, SDO is in high impedance state and it does not interfere with SPI bus activities. Since the NCV78703 always clocks data out on the falling edge and samples data in on rising edge of clock, the MCU SPI port must be configured to match this operation.

The implemented SPI allows connection to multiple slaves by means of star connection (CSB per slave) or by means of daisy chain.

An SPI star connection requires a bus = (3 + N) total lines, where N is the number of Slaves used, the SPI frame length is 16 bits per communication.

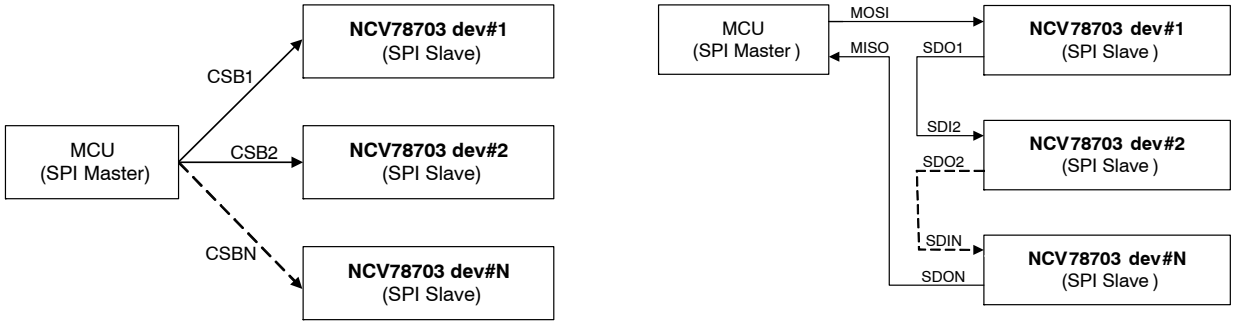


Figure 18. SPI Star vs. Daisy Chain Connection

SPI Daisy chain mode

SPI daisy chain connection bus width is always four lines independently on the number of slaves. However, the SPI transfer frame length will be a multiple of the base frame length so N x 16 bits per communication: the data will be interpreted and read in by the devices at the moment the CSB rises.

A diagram showing the data transfer between devices in daisy chain connection is given further: CMDx represents the 16−bit command frame on the data input line transmitted by the Master, shifting via the chips' shift registers through the daisy chain. The chips interpret the command once the chip select line rises.

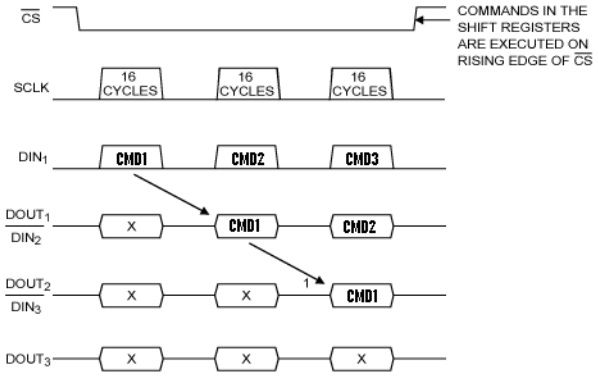


Figure 19. SPI Daisy Chain Data Shift Between Slaves. The symbol 'x' represents the previous content of the SPI shift register buffer.

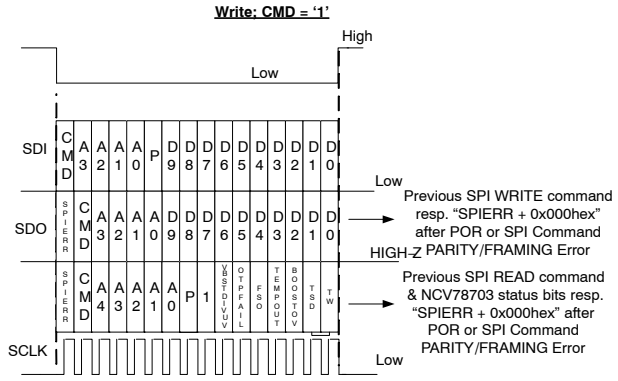
The NCV78703 default power up communication mode is “star”. In order to enable daisy chain mode, a multiple of 16 bits clock cycles must be sent to the devices, while the SDI line is left to zero.

Note: to come back to star mode the NOP register (address 0x0000) must be written with all ones, with the proper data parity bit and parity framing bit: see SPI protocol for details about parity and write operation.

SPI Transfer Format

Two types of SPI commands (to SDI pin of NCV78703) from the micro controller can be distinguished: “Write to a control register” and “Read from register (control or status)”.

The frame protocol for the *write operation*:




```
P  =  not(CMD xor A3 xor A2 xor A1 xor A0 xor D9 xor D8 xor D7 xor
      D6  xor D5 xor D4 xor D3 xor D2 xor D1 xor D0)
```

Figure 20. SPI Write Frame

Referring to the previous picture, the write frame coming from the master (into the SDI) is composed from the following fields:

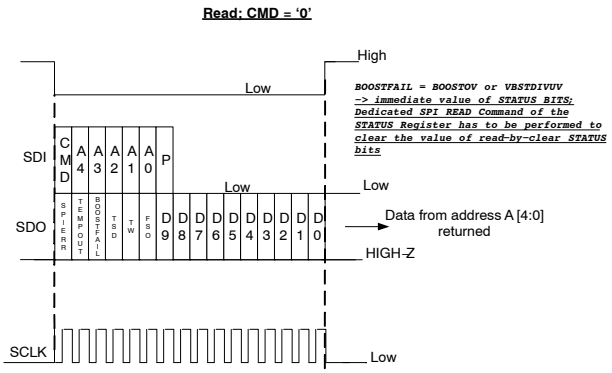
- Bit[15] (MSB): CMD bit = 1 for write operation,
- Bits[14:11]: 4 bits WRITE ADDRESS field,
- Bit[10]: frame parity bit. It is ODD parity formed by the negated XOR of all other bits in the frame,
- Bits[9:0]: 10 bit DATA to write

Device in the same time replies to the master (on the SDO):

- If the previous command was a write and no SPI error had occurred, a copy of the command, address and data written fields,
- If the previous command was a read, the response frame summarizes the address used and an overall diagnostic check (copy of the main detected errors, see Figure 20 and Figure 21 for details),
- In case of previous SPI error or after power−on−reset, only the MSB bit will be 1, followed by zeros.

If parity bit in the frame is wrong, device will not perform command and <SPI> flag will be set.

The frame protocol for the *read operation*:




```
P  =  not(CMD xor A4 xor A3 xor A2 xor A1 xor A0)
```

Figure 21. SPI Read Frame

Referring to the previous picture, the read frame coming from the master (into the SDI) is composed from the following fields:

- Bit[15] (MSB): CMD bit = 0 for read operation,
- Bits[14:10]: 5 bits READ ADDRESS field,
- Bit[10]: frame parity bit. It is ODD parity formed by the negated XOR of all other bits in the frame,
- Bits [8:0]: 9 bits zeroes field.

Device in the same frame provides to the master (on the SDO) data from the required address (in frame response), thus achieving the lowest communication latency.

SPI Framing and Parity Error

SPI communication framing error is detected by the NCV78703 in the following situations:

- Not an integer multiple of 16 CLK pulses are received during the active−low CSB signal;
- LSB bits (8..0) of a read command are not all zero;
- SPI parity errors, either on write or read operation.

Once an SPI error occurs, the <SPI> flag can be reset only by reading the status register in which it is contained (using in the read frame the right communication parity bit).

Table 25. NCV78703 SPI ADDRESS MAP

ADDR	R/W	bit9	bit8	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
0x00	NA	NOP register (read/write operation ignored)									
0x01	R/W	BOOST_DIV3/DIV2	VBOOST_VGATE_THR	VDRIVE_VSETPOINT[3:0]				BOOST_OTA_GAIN[1:0]		BOOST_SKCL[1:0]	
0x02	R/W	0x0	BOOST_SLPCTRL[2:0]			BOOST_VLIMTH3[1:0]		BOOST_VLIMTH2[1:0]		BOOST_VLIMTH1[1:0]	
0x03	R/W	BOOST_MULTI_PHASE_MD[1:0]		BOOST_SRCINV	BOOST_OVERVOLTSD_THR[6:0]						
0x04	R/W	FSO_BST_FREQ[2:0]			BOOST_VSETPOINT[6:0]						
0x05	R/W	TSD_AUT_RCVR_EN	ADC_TEMP_THR[2:0]			FSO_MD[2:0]			BOOST3_EN	BOOST2_EN	BOOST1_EN
0x06	R/W	BOOST_OV_REACT[1:0]		VBOOST_TON_SET[2:0]			VBOOST_TOFF_SET[2:0]			FSO_ENABLE_SEL	VDD_ENA
0x07	R/W	P_DISTRIBUTION2[4:0]					P_DISTRIBUTION1[4:0]				
0x08	R/W	0x0		VDRIVE_UV_THR[2:0]			P_DISTRIBUTION3[4:0]				
0x09	R/W	0x0			OTP_BIAS_H	OTP_BIAS_L	OTP_ADDR[2:0]			OTP_OPERATION[1:0]	
0x0A	R	HWR	ODD PARITY	BOOST3_STATUS	BOOST2_STATUS	BOOST1_STATUS	BOOST_OV	TEMP_OUT	SPIERR	TSD	TW
0x0B	R	0x0	ODD PARITY	ENABLE3_STATUS	ENABLE2_STATUS	ENABLE1_STATUS	VDRIVE_NOK	VBSTDIV_UV	OTP_ACTIVE	OTP_FAIL	FSO
0x0C	R	OTP_DATA[9:0]									
0x0D	R	0x0		REVID[7:0]							
OTHER	R	0x0									

Table 26. BIT DEFINITION

Symbol	MAP position	Description
REGISTER 0x00 (CR): NOP Register, Reset Value (POR) = 0000000000_2		
NOP	Bits [9:0] – ADDR_0x00	NOP register (read/write operation ignored)
REGISTER 0x01 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
BOOST_DIV3/DIV2	Bit 9 – ADDR_0x01	Two or Three Phases Selection
VBOOST_VGATE_THR	Bit 8 – ADDR_0x01	Adjustment of Gate Threshold Voltage for Booster Transistor
VDRIVE_VSETPOINT[3:0]	Bits [7:4] – ADDR_0x01	VDRIVE Voltage
BOOST_OTA_GAIN[1:0]	Bits [3:2] – ADDR_0x01	Error Amplifier Gain
BOOST_SKCL[1:0]	Bits [1:0] – ADDR_0x01	Booster Skip Cycle Settings
REGISTER 0x02 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
BOOST_SLPCTRL[2:0]	Bits [8:6] – ADDR_0x02	Booster Slope Control
BOOST_VLIMTH3[1:0]	Bits [5:4] – ADDR_0x02	Booster phase Current Limitation
BOOST_VLIMTH2[1:0]	Bits [3:2] – ADDR_0x02	Booster phase Current Limitation
BOOST_VLIMTH1[1:0]	Bits [1:0] – ADDR_0x02	Booster phase Current Limitation
REGISTER 0x03 (CR): Booster Settings, Reset Value (POR) = 0001111111_2		
BOOST_MULTI_PHASE_MD[1:0]	Bits [9:8] – ADDR_0x03	Stand Alone /Master/Slave Selection
BOOST_SRCINV	Bit 7 – ADDR_0x03	Booster Clock Inversion
BOOST_OVERVOLTSD_THR[6:0]	Bits [6:0] – ADDR_0x03	Booster Overvoltage Threshold
REGISTER 0x04 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
FSO_BST_FREQ[2:0]	Bits [9:7] – ADDR_0x04	Booster Frequency
BOOST_VSETPOINT[6:0]	Bits [6:0] – ADDR_0x04	Booster Voltage Setpoint
REGISTER 0x05 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
TSD_AUT_RCVR_EN	Bit 9 – ADDR_0x05	Thermal Shutdown Automatic Recovery
ADC_TEMP_THR[2:0]	Bits [8:6] – ADDR_0x05	Temperature Output Threshold

Table 26. BIT DEFINITION

Symbol	MAP position	Description
REGISTER 0x05 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
FSO_MD[2:0]	Bits [5:3] – ADDR_0x05	Fail Safe Operation Mode Selection
BOOST3_EN	Bit 2 – ADDR_0x05	Booster Phase 3 Enable
BOOST2_EN	Bit 1 – ADDR_0x05	Booster Phase 2 Enable
BOOST1_EN	Bit 0 – ADDR_0x05	Booster Phase 1 Enable
REGISTER 0x06 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
BOOST_OV_REACT[1:0]	Bits [9:8] – ADDR_0x06	Booster Overvoltage Reaction
VBOOST_TON_SET[2:0]	Bits [7:5] – ADDR_0x06	Booster Minimal TON
VBOOST_TOFF_SET[2:0]	Bits [4:2] – ADDR_0x06	Booster Minimal TOFF
FSO_ENABLE_SEL	Bit 1 – ADDR_0x06	Function of FSO/ENABLE2 Pin
VDD_ENA	Bit 0 – ADDR_0x06	VDD Active without Enable Pin
REGISTER 0x07 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
P_DISTRIBUTION2[4:0]	Bits [9:5] – ADDR_0x07	Power Distribution phase 2
P_DISTRIBUTION1[4:0]	Bits [4:0] – ADDR_0x07	Power Distribution phase 1
REGISTER 0x08 (CR): Booster Settings, Reset Value (POR) = 0000000000_2		
VDRIVE_UV_THR[2:0]	Bits [9:5] – ADDR_0x08	VDRIVE Undervoltage Threshold
P_DISTRIBUTION3[4:0]	Bits [4:0] – ADDR_0x08	Power Distribution phase 3
REGISTER 0x09 (CR): OTP Operations, Reset Value (POR) = 0000000000_2		
OTP_BIAS_H	Bit 6 – ADDR_0x09	OTP bias high
OTP_BIAS_L	Bit 5 – ADDR_0x09	OTP bias low
OTP_ADDR[2:0]	Bits [4:2] – ADDR_0x09	OTP Address
OTP_OPERATION[1:0]	Bits [1:0] – ADDR_0x09	OTP Operation
REGISTER 0x0A (SR): Booster Status, Reset Value (POR) = $1x000xxxxx_2$		
HWR	Bit 9 – ADDR_0x0A	Hardware Reset Flag
ODD PARITY	Bit 8 – ADDR_0x0A	Odd Parity over Data
BOOST3_STATUS	Bit 7 – ADDR_0x0A	Booster Phase 3 Status
BOOST2_STATUS	Bit 6 – ADDR_0x0A	Booster Phase 2 Status
BOOST1_STATUS	Bit 5 – ADDR_0x0A	Booster Phase 1 Status
BOOST_OV	Bit 4 – ADDR_0x0A	Booster Overvoltage Flag
TEMP_OUT	Bit 3 – ADDR_0x0A	Temperature Output
SPIERR	Bit 2 – ADDR_0x0A	SPI Error
TSD	Bit 1 – ADDR_0x0A	Thermal Shutdown
TW	Bit 0 – ADDR_0x0A	Thermal Warning
REGISTER 0x0B (SR): Booster Status, Reset Value (POR) = $0xxxxxx00x_2$		
ODD PARITY	Bit 8 – ADDR_0x0B	Odd Parity over Data
ENABLE3_STATUS	Bit 7 – ADDR_0x0B	Enable Pin 3 Status
ENABLE2_STATUS	Bit 6 – ADDR_0x0B	Enable Pin 2 Status
ENABLE1_STATUS	Bit 5 – ADDR_0x0B	Enable Pin 1 Status
VDRIVE_NOK	Bit 4 – ADDR_0x0B	VDRIVE Voltage Not OK
VBSTDIV_UV	Bit 3 – ADDR_0x0B	VBOOST Divider Undervoltage Flag
OTP_ACTIVE	Bit 2 – ADDR_0x0B	OTP Active Flag
OTP_FAIL	Bit 1 – ADDR_0x0B	OTP Fail Flag

Table 26. BIT DEFINITION

Symbol	MAP position	Description
REGISTER 0x0B (SR): Booster Status, Reset Value (POR) = $0xxxxxx00x_2$		
FSO	Bit 0 – ADDR_0x0B	Fail Safe Operation Mode Active Flag
REGISTER 0x0C (SR): OTP Data, Reset Value (POR) = 0000000000_2		
OTP_DATA[9:0]	Bits [9:0] – ADDR_0x0C	OTP Data Register
REGISTER 0x0D (SR): Revision ID, Reset Value (POR) = $00xxxxxxxx_2$		
REVID[7:0]	Bits [7:0] – ADDR_0x0D	Revision ID

POR values of status registers are shown in situation that FSO mode is not entered after POR. All latched flags are “cleared by read”. ‘x’ means that value after reset is defined during reset phase (diagnostics) or is trimmed during manufacturing process.

SPI register SPI_REVID[7:0] is used to track the silicon version, following encoding mechanism is used:

- SPI_REVID[7] : 0 for NCV78703
- SPI_REVID[6:4] : Full Mask Version <0 to 7>
- SPI_REVID[3:0] : Metal Tune <0 to 15>

REVID[7:0] for N78703−0 and N703−1 devices is 21hex (NCV78703 = 0, Full Mask Version = 2, Metal Tune = 1)

OTP Memory

Description

The OTP (Once Time Programmable) memory contains 75 bits which bear the most important application dependant parameters and is user programmable via SPI interface. The programming of these bits is typically done at the end of the module manufacturing line.

OTP memory serves to store configuration data for Fail−Safe or Stand−Alone functionality or default configuration of the chip after power−up.

The OTP bits can be programmed only once, this is ensured by dedicated *OTP Lock Bit* which is set during programming.

Table 27. OTP MAP

OTP bits	Connection to SPI register
OTP[1:0]	BOOST_SKCL[1:0]
OTP[3:2]	BOOST_OTA_GAN[1:0]
OTP[7:4]	VDRIVE_VSETPOINT[3:0]
OTP[8]	VBOOST_VGATE_THR
OTP[9]	SPARE = ‘0’
OTP[11:10]	BOOST_VLIMTH1[1:0]
OTP[13:12]	BOOST_VLIMTH2[1:0]
OTP[15:14]	SPARE[1:0]= ‘00’
OTP[17:16]	BOOST_OV_REACT[1:0]
OTP[20:18]	BOOST_SLPCTRL[2:0]
OTP[27:21]	BOOST_OVERVOLTSD_THR[6:0]
OTP[28]	BOOST_SRCINV
OTP[30:29]	BOOST_MULTI_PHASE_MD[1:0]
OTP[37:31]	BOOST_VSETPOINT[6:0]
OTP[40:38]	FSO_BST_FREQ[2:0]
OTP[41]	BOOST1_EN
OTP[42]	BOOST2_EN
OTP[43]	SPARE =’0’
OTP[46:44]	FSO_MD[2:0]
OTP[47]	TSD_AUT_RCVR_EN
OTP[48]	VDD_ENA
OTP[49]	FSO_ENABLE_SEL
OTP[52:50]	VBOOST_TOFF_SET[2:0]
OTP[55:53]	VBOOST_TON_SET[2:0]
OTP[60:56]	P_DISTRIBUTION1[4:0]
OTP[65:61]	P_DISTRIBUTION2[4:0]
OTP[70:66]	SPARE[4:0]=’00000’
OTP[73:71]	VDRIVE_UV[2:0]
OTP[74]	OTP Lock Bit

The OTP bits addressed by SPI register OTP_ADDR[2:0] are accessible (read only) in the SPI register OTP_DATA[9:0] after OTP Refresh operation (OTP_OPERATION[1:0] = 0x1) in the following way:

OTP_ADDR[2:0] = 0x0: OTP_DATA[9:0] = OTP[9:0]

OTP_ADDR[2:0] = 0x1: OTP_DATA[9:0] = OTP[19:10]

OTP_ADDR[2:0] = 0x2: OTP_DATA[9:0] = OTP[29:20]

OTP_ADDR[2:0] = 0x3: OTP_DATA[9:0] = OTP[39:30]

OTP_ADDR[2:0] = 0x4: OTP_DATA[9:0] = OTP[49:40]

OTP_ADDR[2:0] = 0x5: OTP_DATA[9:0] = OTP[59:50]

OTP_ADDR[2:0] = 0x6: OTP_DATA[9:0] = OTP[69:60]

OTP_ADDR[2:0] = 0x7: OTP_DATA[9:0] = {0000 & OTP[74:70]}

OTP Operations

The NCV78703 supports following operations with OTP memory:

- OTP_OPERATION[1:0] = 0x0 or 0x3:
  NOP (no operation),
- OTP_OPERATION[1:0] = 0x1:
  OTP Refresh – refresh of the whole OTP memory (75 bits). Data addressed by SPI register OTP_ADDR[2:0] are available in SPI register OTP_DATA[9:0] after the end of OTP Refresh operation. Duration of OTP Refresh operation should be 46 μs measured from CSB rising edge.
- OTP_OPERATION[1:0] = 0x2:
  OTP Zap – data from SPI register (those listed in Table 27) and *OTP Lock Bit* are programmed into OTP memory. OTP Zap operation is allowed to be performed only once − when *OTP Lock Bit* is unprogrammed. Duration of OTP Zap operation should be 15 ms measured from CSB rising edge.

SPI status bit OTP_ACTIVE is set to “log. 1” when an OTP operation is in progress.

OTP Programming Procedure

Following procedure should be applied to program OTP memory:

- VBB voltage has to be higher than 15.8 V with current capability at least 50 mA. The user has to insure that the right voltage is available in the application. Remark: Lower VBB voltage does not prevent OTP zapping.
- SPI registers listed in Table 27 have to be written with required content.
- Content of the SPI registers (those listed in Table 27) is programmed into the OTP memory by OTP_OPERATION[1:0] = 0x2 SPI write command. *OTP Lock Bit* is programmed automatically at the same time to prevent any further OTP programming.

OTP Programming Verification

OTP_FAIL bit in the SPI status register is set when VBB under−voltage (VBB < VBB_OTP_L) is detected during OTP Zap operation. It is clear by read flag.

The OTP_BIAS_H and OTP_BIAS_L registers are used to check proper OTP programming. After OTP programming, the OTP content has to be the same as

programmed when OTP is read with OTP_BIAS_H = 1 and OTP_BIAS_L = 1.

Following procedure should be applied to verify OTP content:

- VDD voltage has to be kept in range for normal mode operation.
- Write SPI registers OTP_BIAS_L = 1 and OTP_BIAS_H = 0
- Write SPI register OTP_OPERATION[1:0] = 0x1 (OTP Refresh) for all OTP_ADDR[2:0] values and check corresponding OTP_DATA[9:0] content which has to match with previously programmed data
- Write SPI registers OTP_BIAS_L = 0 and OTP_BIAS_H = 1
- Write SPI register OTP_OPERATION[1:0] = 0x1 (OTP Refresh) for all OTP_ADDR[2:0] values and check corresponding OTP_DATA[9:0] content which has to match with previously programmed data
- Programming is considered as successful when no mismatch is observed and OTP_FAIL flag is not set.

PCB Layout Recommendations

This section contains instructions for the NCV78703 PCB layout application design. Although this guide does not claim to be exhaustive, these directions can help the developer to reduce application noise impact and insuring the best system operation. All important areas are highlighted in the following picture:

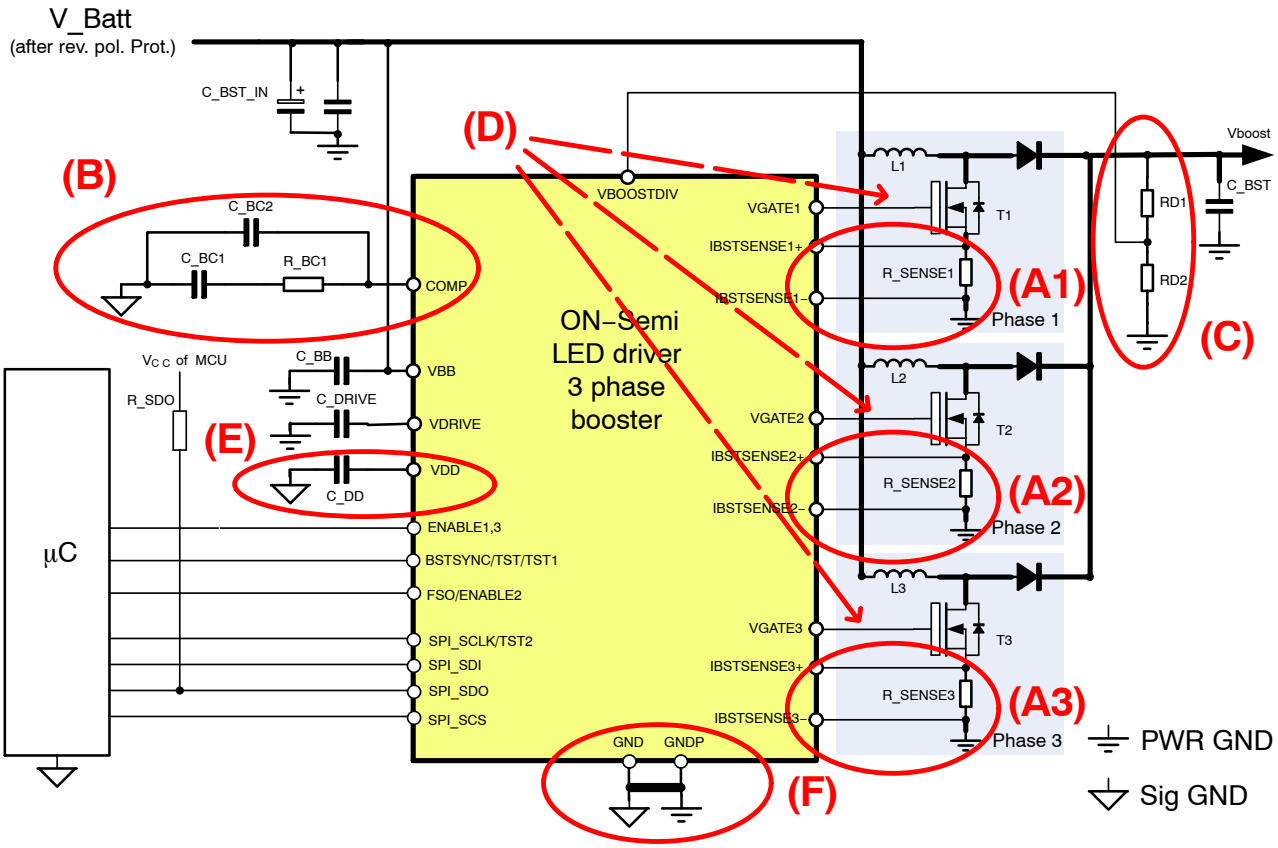


Figure 22. NCV78703 Application Critical PCB Areas

PCB Layout: Booster Current Sensing – Area (A1, A2)

The booster current sensing circuit used both by the loop regulation and the current limitation mechanism, relies on a low voltage comparator, which triggers with respect to the sense voltage across the external resistors R_SENSE1/2. In order to maximize power efficiency (=minimum losses on the sense resistor), the threshold voltage is rather low, with a maximum setting of 100 mV typical. This area may be affected by the MOSFET switching noise if no specific care is taken. The following recommendations are given:

5. Use a four terminals current sense method as depicted in the figure below. The measurement PCB tracks should run in parallel and as close as possible to each other, trying to have the same length. The number of vias along the measurement path should be minimized;
6. Place R_SENSE1/2 sufficiently close to the MOSFET source terminal;
7. The MOSFET's dissipation area should be stretched in a direction away from the sense resistor to minimize resistivity changes due to heating;
8. If the current sense measurement tracks are interrupted by series resistors or jumpers (once as a maximum) their value should be matched and low ohmic (pair of 0 Ω to 47 Ω max) to avoid errors due to the comparator input bias currents.

However, in case of high application noise, a PCB re−layout without RC filters is always recommended.

9. Avoid using the board GND as one of the measurement terminals as this would also introduce errors.

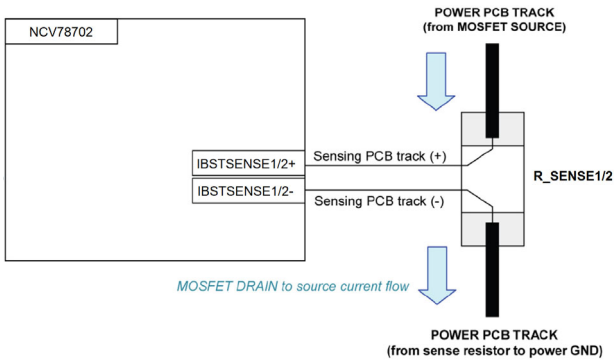


Figure 23. Four Wires Method for Booster Current Sensing Circuit

PCB Layout: Booster Compensation Network – Area (B)

The compensation network must be placed very close to the chip to avoid noise capturing. Its ground has to be connected directly to the chip ground pin to avoid noise coming from other portions of the PCB ground. In addition a ground ring shall provide extra shielding ground around.

PCB Layout: VBOOST Resistor Divider – Area (C)

The VBOOST resistor divider has to be connected directly to the chip BOOST feedback (VBOOSTDIV) pin and ground pin with separate PCB tracks to avoid coupling of the ground shift on the PCB into the chip.

PCB Layout: VGATE Signals – Area (D)

It has to be ensured that VGATE signals do not interfere with other signals like COMP or input of the IMAX or IREG comparators.

PCB Layout: VDD Connections – Area (E)

The VDD decoupling capacitor has to be connected directly to the VDD and ground pins with separate PCB tracks to avoid coupling of the ground shift on the PCB into the chip.

VDD connection from the NCV78703 to the NCV787x3 buck devices should be shielded with surrounding PCB GND.

PCB Layout: GND Connections – Area (F)

The NCV78703 GND and GNDP pins must be connected together. It is suggested to perform this connection directly close to the device, behaving also as the cross−junction between the signal GND (all low power related functions) and the power GNDP (ground of VGATE driver). The device exposed pad should be connected to the GND plane for dissipation purposes.

PCB Layout: Additional EMC Recommendations on Loops

It is suggested in general to have a good metal connection to the ground and to keep it as continuous as possible, not interrupted by resistors or jumpers.

In additions, PCB loops for power lines should be minimized. A simplified application schematic is shown in the next figure to better focus on the theoretical explanation. When a DC voltage is applied to the VBB, at the left side of the boost inductor L_BOOST, a DC voltage also appears on the right side of L_BUCK and on the C_BUCK. However, due to the switching operation (boost and buck), the applied voltage generates AC currents flowing through the red area (1). These currents also create time variable voltages in the area marked in green (2). In order to minimize the radiation due to the AC currents in area 1, the tracks' length between L_BOOST and the pair L_BUCK plus C_BUCK must be kept low. At the contrary, if long tracks would be used, a bigger parasitic capacitance in area 2 would be created, thus increasing the coupled EMC noise level.

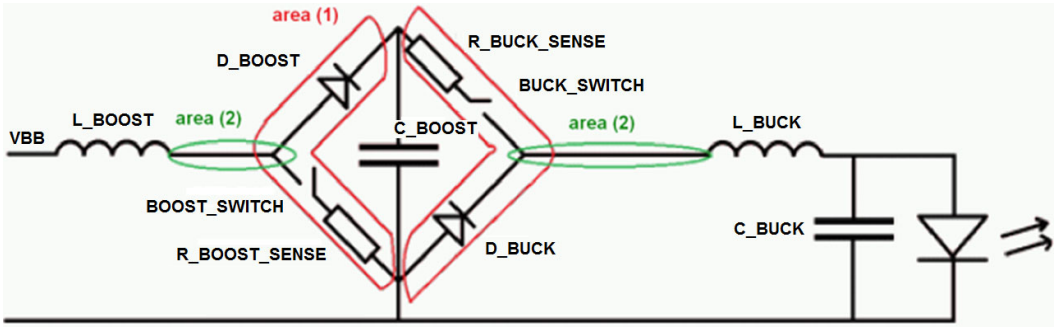


Figure 24. PCB AC Current Lines (1) and AC Voltage Nodes (2)

Table 28. ORDERING INFORMATION

Device	Marking	Package*	Shipping†
NCV78703MW0R2G	N78703−0	QFN24 5 × 5 with Wettable Flank (Pb-Free)	5000 / Tape & Reel
NCV78703MW1R2G	N703−1	QFN24 4 × 4 with Wettable Flank (Pb-Free)	2500 / Tape & Reel

*For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

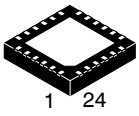
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

MECHANICAL CASE OUTLINE
PACKAGE DIMENSIONS

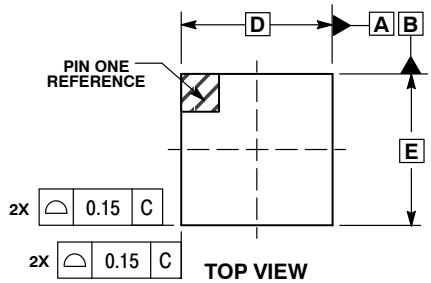
ON Semiconductor®

QFN24 5x5, 0.65P
CASE 485CS
ISSUE O

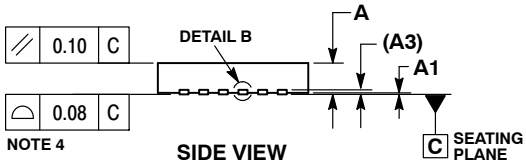
DATE 24 OCT 2012



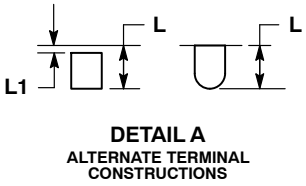
SCALE 2:1



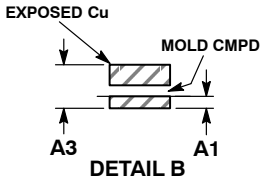
TOP VIEW



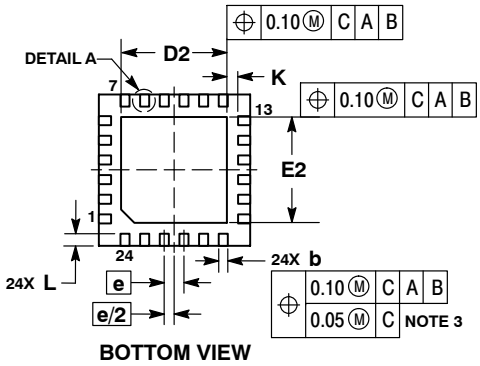
SIDE VIEW



DETAIL A
ALTERNATE TERMINAL CONSTRUCTIONS

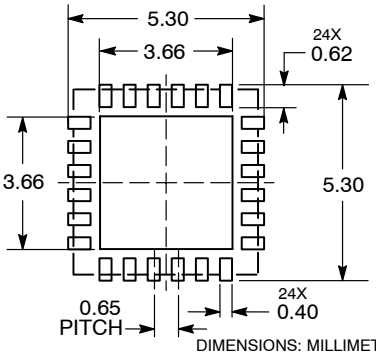


DETAIL B
ALTERNATE CONSTRUCTION



BOTTOM VIEW

SOLDERING FOOTPRINT*



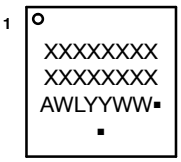
DIMENSIONS: MILLIMETERS

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

NOTES:
1. DIMENSIONS AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.15 AND 0.30 MM FROM THE TERMINAL TIP.
4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.

	MILLIMETERS	
DIM	MIN	MAX
A	0.80	0.90
A1	−−−	0.05
A3	0.20 REF	
b	0.25	0.35
D	5.00 BSC	
D2	3.40	3.60
E	5.00 BSC	
E2	3.40	3.60
e	0.65 BSC	
K	0.20 MIN	
L	0.30	0.50
L1	−−−	0.15

GENERIC MARKING DIAGRAM*



XXXXX = Specific Device Code
A = Assembly Location
WL = Wafer Lot
YY = Year
WW = Work Week
▪ = Pb−Free Package

(Note: Microdot may be in either location)

*This information is generic. Please refer to device data sheet for actual part marking.
Pb−Free indicator, “G” or microdot “ ▪”, may or may not be present.

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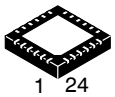
DESCRIPTION:	**QFN24, 5x5, 0.65P**		**PAGE 1 OF 1**

MECHANICAL CASE OUTLINE
PACKAGE DIMENSIONS

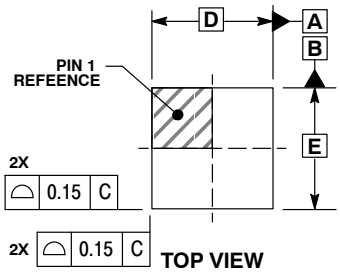
ON Semiconductor®

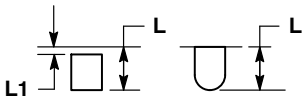
QFN24, 4x4, 0.5P
CASE 485L
ISSUE B

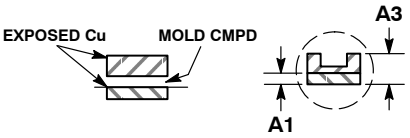
DATE 05 JUN 2012

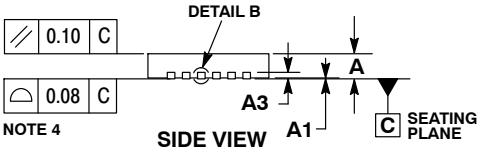


SCALE 2:1



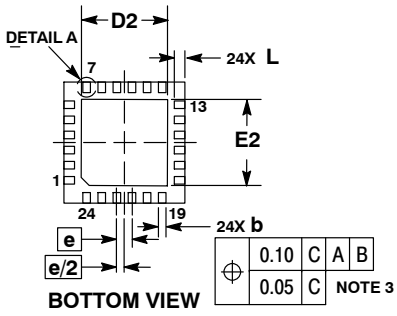






NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.25 AND 0.30 MM FROM THE TERMINAL TIP.
4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.

	MILLIMETERS	
DIM	MIN	MAX
A	0.80	1.00
A1	0.00	0.05
A3	0.20 REF	
b	0.20	0.30
D	4.00 BSC	
D2	2.70	2.90
E	4.00 BSC	
E2	2.70	2.90
e	0.50 BSC	
L	0.30	0.50
L1	0.05	0.15



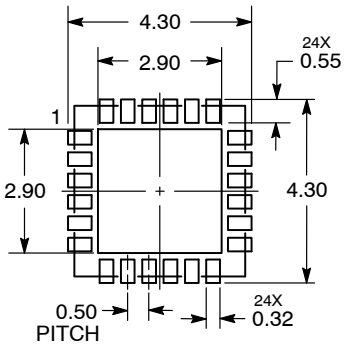
GENERIC MARKING DIAGRAM*

XXXXX = Specific Device Code
A = Assembly Location
L = Wafer Lot
Y = Year
W = Work Week
▪ = Pb−Free Package

(Note: Microdot may be in either location)

*This information is generic. Please refer to device data sheet for actual part marking. Pb−Free indicator, “G” or microdot “ ▪”, may or may not be present.

RECOMMENDED SOLDERING FOOTPRINT



DIMENSIONS: MILLIMETERS

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DESCRIPTION:	**QFN24, 4X4, 0.5P**		**PAGE 1 OF 1**

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