Application Note

AN2533/D
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Standard Space Vector Modulation – 3 outputs version – XOR version TPU Function Set (svmStd3Xor)

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Functional Overview

Standard Space Vector Modulation – 3 outputs version – XOR version (svmStd3Xor) is a version of the Standard Space Vector Modulation – 3 output version (svmStd3) function that uses two TPU channels to generate one PWM output channel. The TPU channel outputs are connected to an XOR gate whos output is the required PWM signal. See **Figure 1**. An advantage of this solution is the full range 0% to 100% of PWM duty-cycle ratios. There is no MPW (minimum pulse width) parameter to limit the edge duty-cycle ratios in this version, unlike in the svmStd3. A disadvantage is that the number of assigned TPU channels is doubled.

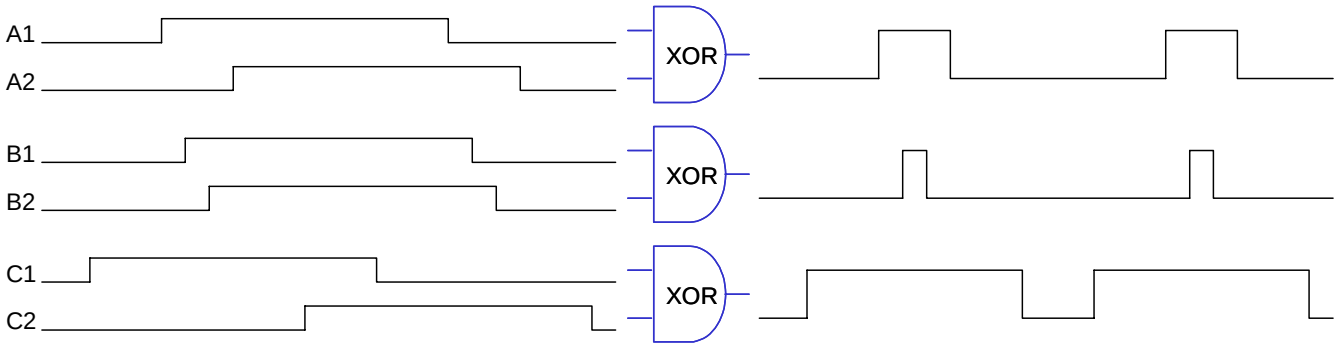

Figure 1. Functionality of XOR version – illustration

The function set consists of 5 TPU functions:

- Standard Space Vector Modulation – 3 outputs version – XOR version – R channels (svmStd3Xor_R)
- Standard Space Vector Modulation – 3 outputs version – XOR version – T channels (svmStd3Xor_T)

- Synchronization Signal for Standard Space Vector Modulation – 3 outputs version – XOR version (svmStd3Xor_sync)
- Resolver Reference Signal for Standard Space Vector Modulation – 3 outputs version – XOR version (svmStd3Xor_res)
- Fault Input for Standard Space Vector Modulation – 3 outputs version – XOR version (svmStd3Xor_fault)

The svmStd3Xor function generates 3 pairs of XOR gate input signals. The XOR gate outputs then produce a 3-channel 3-phase center-aligned PWM signal. The generated signals control external hardware, which outputs pair of transistor signals (top and bottom) with dead-time inserted. The Synchronization Signal for the svmStd3Xor function can be used to generate one or more adjustable signals for a wide range of uses, that are synchronized to the PWM, and track changes in the PWM period. The Resolver Reference Signal for the svmStd3Xor function can be used to generate one or more 50% duty-cycle adjustable signals that are also synchronized to the PWM. The Fault Input for the svmStd3Xor function is a TPU input function that sets all XOR gate outputs low when the input signal goes low.

Function Set Configuration

None of the TPU functions in the Standard Space Vector Modulation – 3 outputs version – XOR version TPU function set can be used separately. The svmStd3Xor_R and svmStd3Xor_T functions have to be used together. The svmStd3Xor_R runs on pins A1, B1, C1, and the svmStd3Xor_T runs on pins A2, B2, C2 – see **Figure 1**. One or more channels running Synchronization Signal for svmStd3Xor as well as Resolver Reference Signals for svmStd3Xor functions can be added to the svmStd3Xor_R and svmStd3Xor_T functions. They can run with different settings on each channel. The function Fault Input for svmStd3Xor can also be added to the svmStd3Xor_R and svmStd3Xor_T functions. It is recommended to use it on channel 15, and to set the hardware option that disables all TPU output pins when the channel 15 input signal is low (DTPU bit = 1). This ensures that the hardware reacts quickly to a pin fault state. Note that it is not only the svmStd3Xor_R and svmStd3Xor_T channels, but all TPU output channels, including the synchronization signals, that are disabled in this configuration.

Table 1 shows the configuration options and restrictions.

Table 1. svmStd3Xor TPU function set configuration options and restrictions

TPU function	Optional/ Mandatory	How many channels	Assignable channels
svmStd3Xor_R	mandatory	3	any 3 channels
svmStd3Xor_T	mandatory	3	any 3 channels
svmStd3Xor_sync	optional	1 or more	any channels
svmStd3Xor_res	optional	1 or more	any channels
svmStd3Xor_fault	optional	1	any, recommended is 15 and DTPU bit set

Table 2 shows an example of configuration.

Table 2. Example of configuration

Channel	TPU function	Priority
0	svmStd3Xor_R	middle
1	svmStd3Xor_T	middle
2	svmStd3Xor_R	middle
3	svmStd3Xor_T	middle
4	svmStd3Xor_R	middle
5	svmStd3Xor_T	middle
13	svmStd3Xor_sync	low
14	svmStd3Xor_res	low
15	svmStd3Xor_fault	high

Table 3 shows the TPU function code sizes.

Table 3. TPU function code sizes.

TPU function	Code size
svmStd3Xor_R	216 µ instructions + 8 entries = 224 long words
svmStd3Xor_T	3 µ instructions + 8 entries = 11 long words
svmStd3Xor_sync	26 µ instructions + 8 entries = 34 long words
svmStd3Xor_res	38 µ instructions + 8 entries = 46 long words
svmStd3Xor_fault	9 µ instructions + 8 entries = 17 long words

Configuration Order

The CPU configures the TPU as follows.

1. Disables the channels by clearing the two channel priority bits on each channel used (not necessary after reset).
2. Selects the channel functions on all used channels by writing the function numbers to the channel function select bits.

3. Initializes function parameters. The parameters *T*, *prescaler*, *SQRT3*, *CPU14* and *sync_presc_addr* must be set before initialization. If an svmStd3Xor_sync channel or an svmStd3Xor_res channel is used, then its parameters must also be set before initialization.
4. Issues an HSR (Host Service Request) type %10 to one of the svmStd3Xor_R channels to initialize all svmStd3Xor_R and svmStd3Xor_T channels. Issues an HSR type %10 to the svmStd3Xor_sync channels, svmStd3Xor_res channels and svmStd3Xor_fault channel, if used.
5. Enables servicing by assigning high, middle or low priority to the channel priority bits. All svmStd3Xor_R and svmStd3Xor_T channels must be assigned the same priority to ensure correct operation. The CPU must ensure that the svmStd3Xor_sync or svmStd3Xor_res channels are initialized after the initialization of the svmStd3Xor_R and svmStd3Xor_T channels:
   - assign a priority to the svmStd3Xor_R and svmStd3Xor_T channels to enable their initialization
   - if a Synchronization Signal or a Resolver Reference Signal channel is used, wait until the HSR bits are cleared to indicate that initialization of the svmStd3Xor_R and svmStd3Xor_T channels has completed and
   - assign a priority to the svmStd3Xor_sync or svmStd3Xor_res channels to enable their initialization

NOTE: *A CPU routine that configures the TPU can be generated automatically using the MPC500_Quick_Start Graphical Configuration Tool.*

Detailed Function Description

Standard Space Vector Modulation – 3 outputs version – XOR version – R channels (svmStd3Xor_R) and Standard Space Vector Modulation – 3 outputs version – XOR version – T channels (svmStd3Xor_T)

The svmStd3Xor_R and svmStd3Xor_T TPU functions work together to generate 3 pairs of XOR gate inputs. The XOR gate outputs then produce a 3-channel 3-phase center-aligned PWM signal. Unlike the svmStd, the generated signals are not top-bottom pairs with dead-times but only top-like signals without dead-times. In order to charge the bootstrap transistors, the PWM signals start to run 1.6ms after their initialization (at 20MHz TCR1 clock). The functions generate signals corresponding to Reference Voltage Vector Amplitude of 0 (50% duty-cycle) until the first reloaded values are processed.

The CPU controls the PWM output by setting the TPU parameters. The Stator Reference Voltage Vector components $u_{\acute{a}}$ and $u_{\hat{a}}$ have to be adjusted during run time. The PWM period *T* and the *prescaler* – the number of PWM periods per reload of new values – are also read at each reload, so these parameters can be changed during run time. The CPU notifies the TPU that the new reload

values are prepared by setting the LD_OK parameter. The TPU notifies the CPU that the reload values have been read and new values can be written by clearing the LD_OK parameter.

The TPU writes the parameter Sector that indicates the current Stator Reference Voltage Vector position in sector 1 to 6.

The following figures show the input Stator Reference Voltage Vector components $u_{\hat{a}}$ and $u_{\hat{a}}$, corresponding sectors and output PWM signal duty cycle ratios:

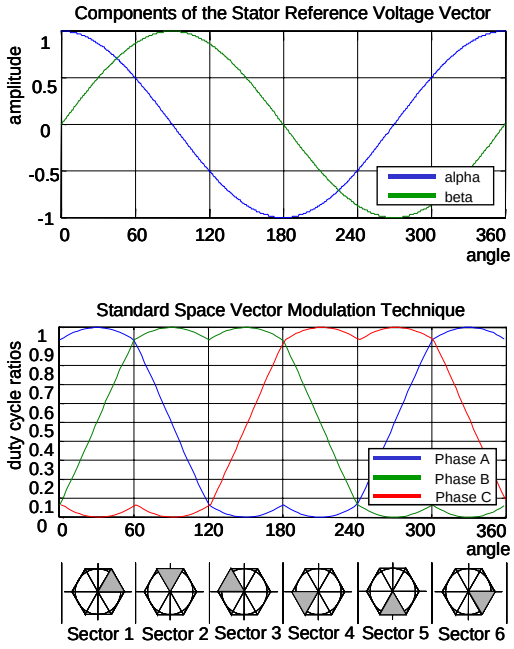

Figure 2. Standard Space Vector Modulation Technique

The following equations describe how the Space Vector Modulation PWM signal high-times ht_A, ht_B, ht_C and transition times t_{trans} of each channel are calculated:

$$U_\beta = T \cdot u_\beta$$

$$U_\alpha = T \cdot u_\alpha$$

$$X = U_\beta$$

$$Y = \frac{U_\beta + U_\alpha\sqrt{3}}{2}$$

$$Z = \frac{U_\beta - U_\alpha\sqrt{3}}{2}$$

	Y < 0			Y >= 0		
	Z < 0	Z >= 0		Z < 0		Z >= 0
		X <= 0	X > 0	X <= 0	X > 0	
Sector:	**V.**	**IV.**	**III.**	**VI.**	**I.**	**II.**

Host Interface

Written By CPU

Written by both CPU and TPU

Written By TPU

Not Used

Table 4. svmStd3Xor_T Control Bits

Name	Options
3 2 1 0 Channel Function Select	svmStd3Xor_T function number (Assigned during assembly the DPTRAM code from library TPU functions)
1 0 Channel Priority	00 – Channel Disabled 01 – Low Priority 10 – Middle Priority 11 – High Priority
1 0 Host Service Bits (HSR)	00 – No Host Service Request 01 – Not used 10 – Not used 11 – Not used
1 0 Host Sequence Bits (HSQ)	xx – Not used
0 Channel Interrupt Enable	x – Not used
0 Channel Interrupt Status	x – Not used

Table 5. svmStd3Xor_R Control Bits

Name	Options
3 2 1 0 Channel Function Select	svmStd3Xor_R function number (Assigned during assembly the DPTRAM code from library TPU functions)
1 0 Channel Priority	00 – Channel Disabled 01 – Low Priority 10 – Middle Priority 11 – High Priority
1 0 Host Service Bits (HSR)	00 – No Host Service Request 01 – Not used 10 – Initialization 11 – Stop

Table 5. svmStd3Xor_R Control Bits

Name	Options
1 0 Host Sequence Bits (HSQ)	xx – Not used
0 Channel Interrupt Enable	0 – Channel Interrupt Disabled 1 – Channel Interrupt Enabled
0 Channel Interrupt Status	0 – Interrupt Not Asserted 1 – Interrupt Asserted

TPU function svmStd3Xor_R generates an interrupt when the current values of *Ualfa*, *Ubeta*, *T* and *prescaler* have been read by TPU and indicates to the CPU that it can write new variables. The CPU program can either wait for this interrupt to occur, or poll the *LD_OK* bit to check it has cleared. The interrupt is generated at each reload by one of the R channels. The T channels do not generate any interrupts.

Table 6. svmStd3Xor_T and svmStd3Xor_R Parameter RAM

Channel	Parameter	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Phase A 1 channel	0	htA															
	1	x2_chan_A															
	2	x1a_chan_A															
	3	x1b_chan_A															
	4	Ualfa															
	5	Ubeta															
	6																
	7	fault_pinstate															
Phase A 2 channel	0	Ttime_A2															
	1	T_copy															
	2	prsc_copy															
	3	UA															
	4	LD_OK															
	5	Sector															
	6																
	7																

Table 6. svmStd3Xor_T and svmStd3Xor_R Parameter RAM

Channel	Parameter	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Phase B 1 channel	0	htB															
	1	x2_chan_B															
	2	x1a_chan_B															
	3	x1b_chan_B															
	4	T															
	5	prescaler															
	6																
	7																
Phase B 2 channel	0	Ttime_B2															
	1	dec															
	2	UA3															
	3	UB															
	4	SQRT3															
	5	sync_presc_addr															
	6																
	7																
Phase C 1 channel	0	htC															
	1	x2_chan_C															
	2	x1a_chan_C															
	3	x1b_chan_C															
	4	CPU14															
	5																
	6																
	7																
Phase C 2 channel	0	Ttime_C2															
	1	state															
	2	center_time															
	3																
	4																
	5																
	6																
	7																

Table 7. svmStd3Xor_T and svmStd3Xor_R parameter description

Parameter	Format	Description
Parameters written by CPU		
Ualfa, Ubeta	16-bit fractional	Stator Reference Voltage Vector components
T	16-bit unsigned integer	PWM period in number of TCR1 TPU cycles
prescaler	16-bit unsigned integer	The number of PWM periods per reload of new values

Table 7. svmStd3Xor_T and svmStd3Xor_R parameter description

Parameter	Format	Description
CPU14	16-bit unsigned integer	Time of 14 IMB clocks in TCR1 clocks.
SQRT3	16-bit fractional	sqrt(3)/2 = 0.866 = $6EDA constant
sync_presc_addr	8-bit unsigned integer	address of synchronization channel *prescaler* parameter: $X4, where X is synchronization channel number. $0 if no synchronization channel is used.
Parameters written by both TPU and CPU		
LD_OK	1-bit	0 ... CPU can update variables 1 ... TPU can read variables CPU sets 1, TPU sets 0
Parameters written by TPU		
Sector	16-bit unsigned integer	The position of Stator Reference Voltage Vector in a sector. The Sector can be 1, 2, 3, 4, 5 or 6
fault_pinstate	0 or 1	If fault channel is used, state of fault pin: 0 ... low 1 ... high
Other parameters are just for TPU function inner use.		

Performance

Table 8. svmStd3Xor_T State Statistics

State	Max IMB Clock Cycles	RAM Accesses by TPU
ST	2	1
SF	2	0

Table 9. svmStd3Xor_R State Statistics

State	Max IMB Clock Cycles	RAM Accesses by TPU
INIT	92	25
STOP	82	4
SFR_0	6	1
SFR	40	14
C5	16	4
SFC_0	6	1
SFC	56	11

NOTE: *Execution times do not include the time slot transition time (TST = 10 or 14 IMB clocks)*

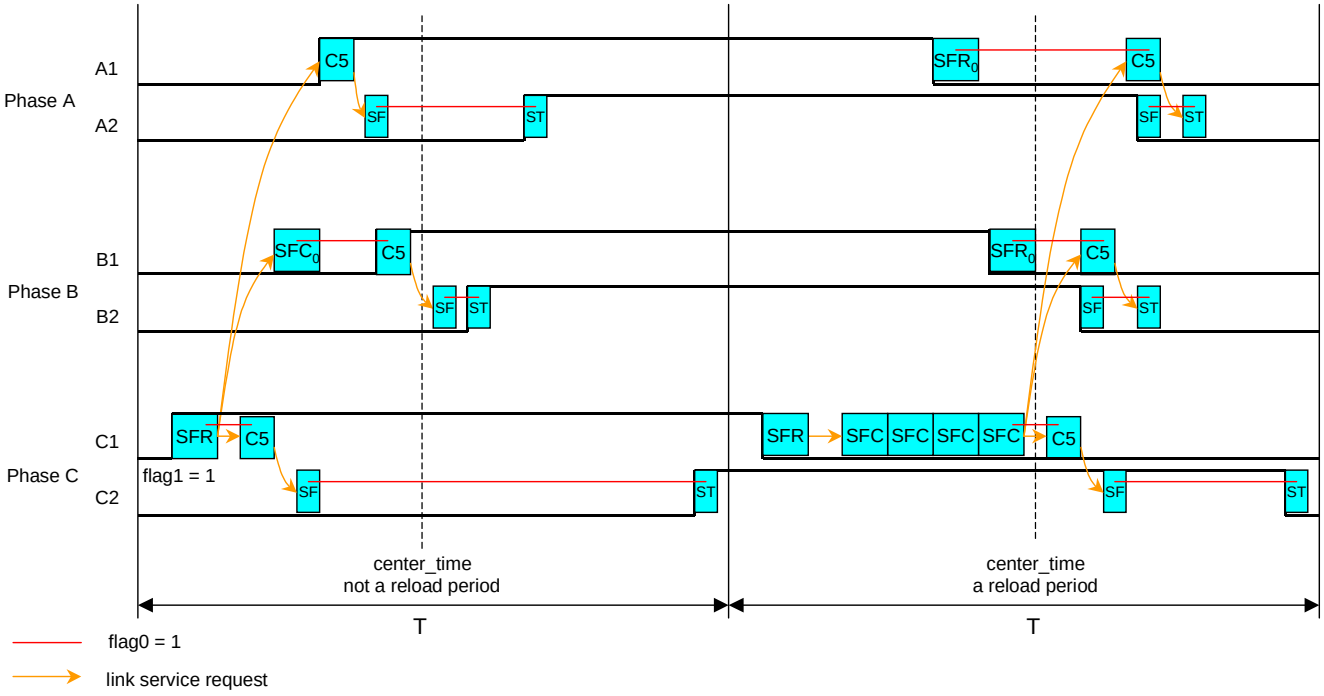

Figure 3. svmStd3Xor_T and svmStd3Xor_R timing

NOTE: *The R channel with the momentary earliest transition within the PWM period is marked by a flag1 and runs the SFR and SFC states.*

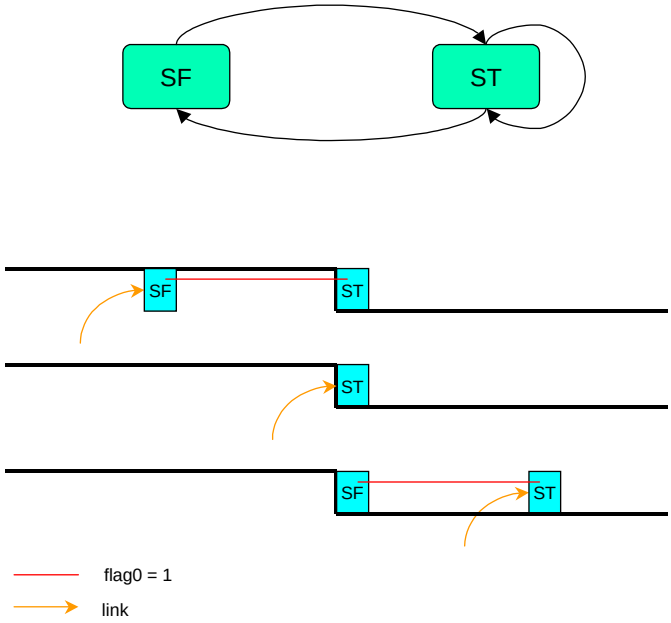

Figure 4. svmStd3Xor_T state diagram and 3 cases of timing

NOTE: *Which case happens is determined by the time when the link comes.*

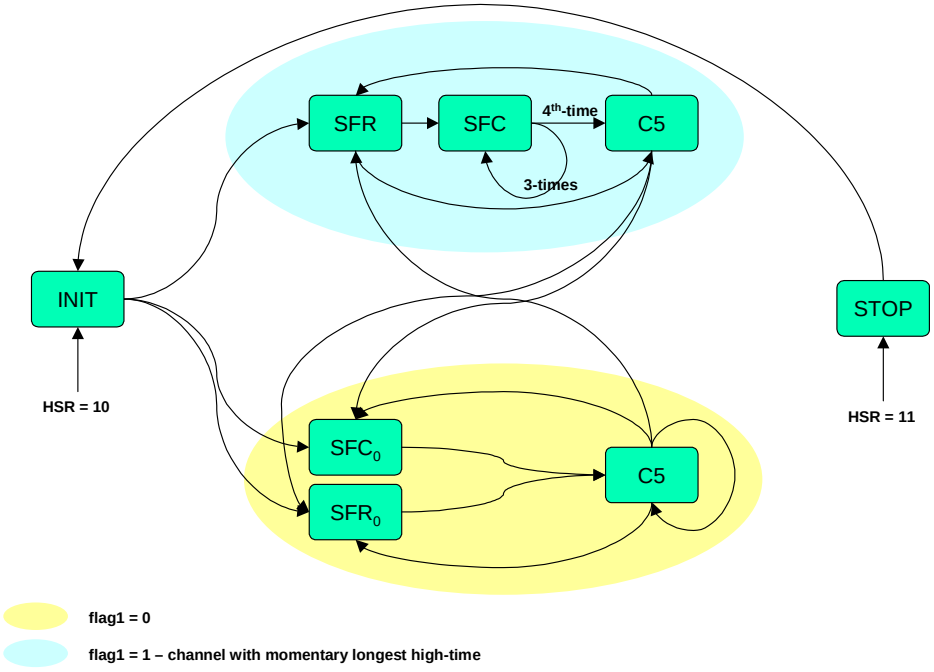

Figure 5. svmStd3Xor_R state diagram

Synchronization signal for Standard Space Vector Modulation – 3 outputs version – XOR version (svmStd3Xor_sync)

The svmStd3Xor_sync TPU function uses information obtained from svmStd3Xor_R and svmStd3Xor_T functions, the actual PWM center times and the PWM periods. This allows a signal to be generated, which tracks the changes in the PWM period and is always synchronized with the PWM. The synchronization signal is a positive pulse generated repeatedly after the *prescaler* or *presc_copy* PWM periods (see next paragraph). The low to high transition of the pulse can be adjusted by a parameter, either negative or positive, to go a number of TCR1 TPU cycles before or after the PWM period center time. The pulse width *pw* is another synchronization signal parameter.

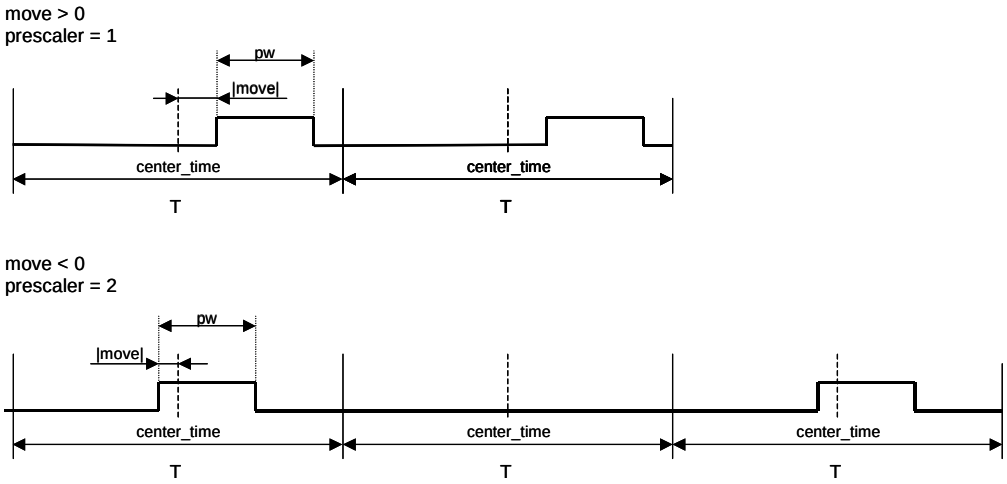

Figure 6. Synchronization signal adjustment examples

Synchronized Change of PWM Prescaler And Synchronization Signal Prescaler

The svmStd3Xor_sync TPU function actually uses the *presc_copy* parameter instead of the *prescaler* parameter. The *prescaler* parameter holds the prescaler value that is copied to the *presc_copy* by the svmStd3Xor_bottom function at the time the PWM parameters are reloaded. This ensures that new prescaler values for the PWM signals, as well as the synchronization signal, are applied at the same time. Write the synchronization signal *prescaler* parameter address to the *sync_presc_addr* parameter to enable this mechanism. Write 0 to disable it, and remember to set the synchronization signal *presc_copy* parameter instead of the *prescaler* parameter in this case.

Host Interface

Written By CPU

Written by both CPU and TPU

Written By TPU

Not Used

Table 10. svmStd3Xor_sync Control Bits

Name	Options
3 2 1 0 Channel Function Select	svmStd3Xor_sync function number (Assigned during assembly the DPTRAM code from library TPU functions)
1 0 Channel Priority	00 – Channel Disabled 01 – Low Priority 10 – Middle Priority 11 – High Priority

Table 10. svmStd3Xor_sync Control Bits

Name	Options
1 0 Host Service Bits (HSR)	00 – No Host Service Request 01 – Not used 10 – Initialization 11 – Not used
1 0 Host Sequence Bits (HSQ)	xx – Not used
0 Channel Interrupt Enable	0 – Channel Interrupt Disabled 1 – Channel Interrupt Enabled
0 Channel Interrupt Status	0 – Interrupt Not Asserted 1 – Interrupt Asserted

TPU function svmStd3Xor_sync generates an interrupt after each low to high transition.

Table 11. svmStd3Xor_sync Parameter RAM

Channel	Parameter	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Synchronization channel	0	move															
	1	pw															
	2	prescaler															
	3	presc_copy															
	4	time															
	5	dec															
	6	T_copy															
	7																

Table 12. svmStd3Xor_sync parameter description

Parameter	Format	Description
Parameters written by CPU		
move	16-bit signed integer	The number of TCR1 TPU cycles to forego (negative) or come after (positive) the PWM period center time
pw	16-bit unsigned integer	Synchronization pulse width in number of TCR1 TPU cycles.

Table 12. svmStd3Xor_sync parameter description

Parameter	Format	Description
prescaler	16-bit unsigned integer	The number of PWM periods per synchronization pulse – use in case of synchronized prescalers change
presc_copy	16-bit unsigned integer	The number of PWM periods per synchronization pulse – use in case of asynchronized prescalers change
Parameters written by TPU		
Other parameters are just for TPU function inner use.		

Performance

There is one limitation. The absolute value of parameter *move* has to be less than a quarter of the PWM period *T*.

$$|move| < \frac{T}{4}$$

Table 13. svmStd3Xor_sync State Statistics

State	Max IMB Clock Cycles	RAM Accesses by TPU
INIT	12	5
S1	12	6
S2	8	3
S3	16	7

NOTE: *Execution times do not include the time slot transition time (TST = 10 or 14 IMB clocks)*

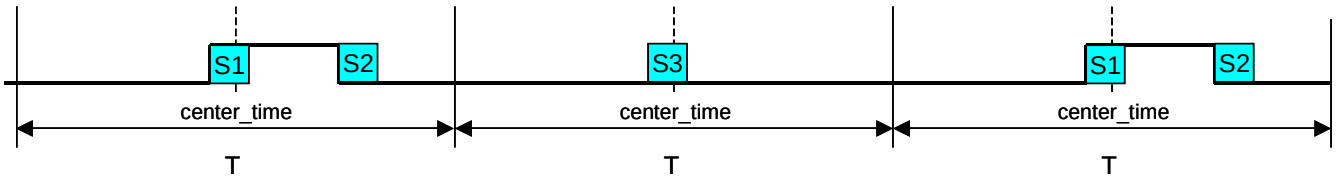

Figure 7. svmStd3Xor_sync timing

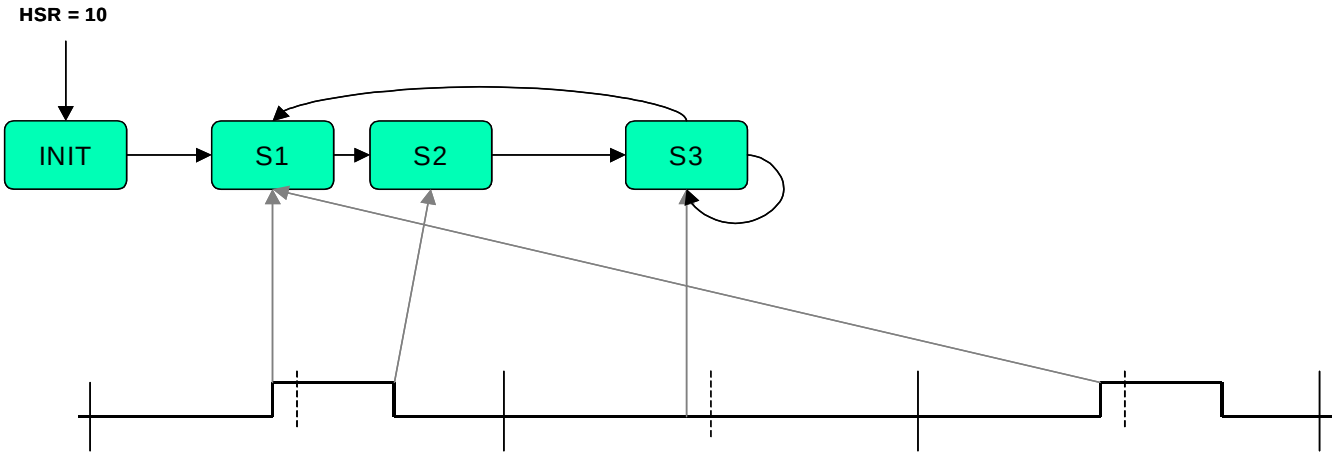

Figure 8. svmStd3Xor_sync state diagram

Resolver Reference Signal for Standard Space Vector Modulation – 3 outputs version – XOR version (svmStd3Xor_res)

The svmStd3Xor_res TPU function uses information read from the svmStd3Xor_R and svmStd3Xor_T functions, the actual PWM center times and the PWM periods. This allows a signal to be generated, which tracks the changes of the PWM period and is always synchronized with the PWM. The resolver reference signal is a 50% duty-cycle signal with a period equal to *prescaler* or synchronization channel *presc_copy* PWM periods (see next paragraph). The low to high transition of the pulse can be adjusted by a parameter, either negative or positive, to go a number of TCR1 TPU cycles before or after the PWM period center time.

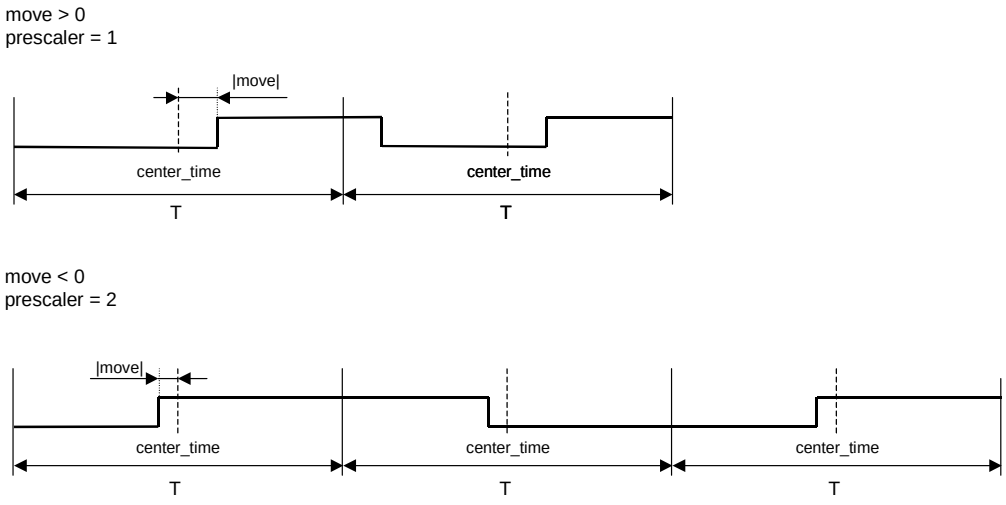

Figure 9. Resolver reference signal adjustment examples

Synchronized Change of PWM Prescaler And Resolver Reference Signals Prescaler

The svmStd3Xor_res TPU function can inherit the Synchronization Signal prescaler that is synchronously changed with the PWM prescaler. Write the synchronization signals *presc_copy* parameter address to the *presc_addr* parameter to enable this mechanism. Write 0 to disable it, and in this case set the *prescaler* parameter to directly specify prescaler value.

Host Interface

Written By CPU

Written by both CPU and TPU

Written By TPU

Not Used

Table 14. svmStd3Xor_res Control Bits

Name	Options
3 2 1 0 Channel Function Select	svmStd3Xor_res function number (Assigned during assembly the DPTRAM code from library TPU functions)
1 0 Channel Priority	00 – Channel Disabled 01 – Low Priority 10 – Middle Priority 11 – High Priority
1 0 Host Service Bits (HSR)	00 – No Host Service Request 01 – Not used 10 – Initialization 11 – Not used
1 0 Host Sequence Bits (HSQ)	xx – Not used
0 Channel Interrupt Enable	x – Not used
0 Channel Interrupt Status	x – Not used

Table 15. svmStd3Xor_res Parameter RAM

Channel	Parameter	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Resolver	0	move															
	1																
	2	presc_addr															
	3	prescaler															
	4	time															
	5	dec															
	6	T_copy															
	7																

Table 16. svmStd3Xor_res parameter description

Parameter	Format	Description
Parameters written by CPU		
move	16-bit signed integer	The number of TCR1 TPU cycles to forego (negative) or come after (positive) the PWM period center time
presc_addr	16-bit unsigned integer	$00X6, where X is a number of Synchronization Signal channel, to inherit Sync. channel prescaler or $0000 to enable direct specification of prescaler value in prescaler parameter
prescaler	1, 2, 4, 6, 8, 10, 12, 14, ...	The number of PWM periods per synchronization pulse – use when apresc_addr = 0
Parameters written by TPU		
Other parameters are just for TPU function inner use.		

Performance

There is one limitation. The absolute value of parameter *move* has to be less than a quarter of the PWM period *T*.

$$|move| < \frac{T}{4}$$

Table 17. svmStd3Xor_res State Statistics

State	Max IMB Clock Cycles	RAM Accesses by TPU
INIT	12	5
S1	26	9
S3	18	7

NOTE: *Execution times do not include the time slot transition time (TST = 10 or 14 IMB clocks)*

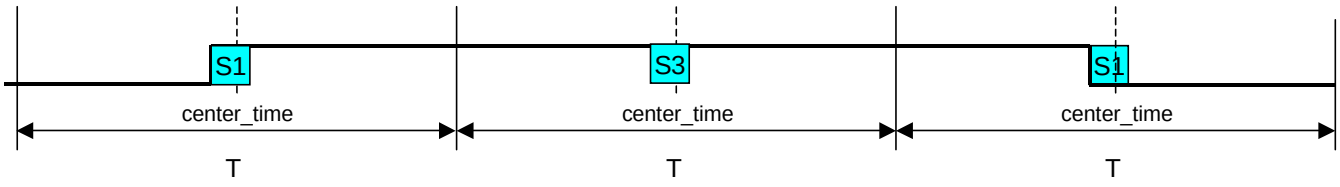

Figure 10. svmStd3Xor_res timing

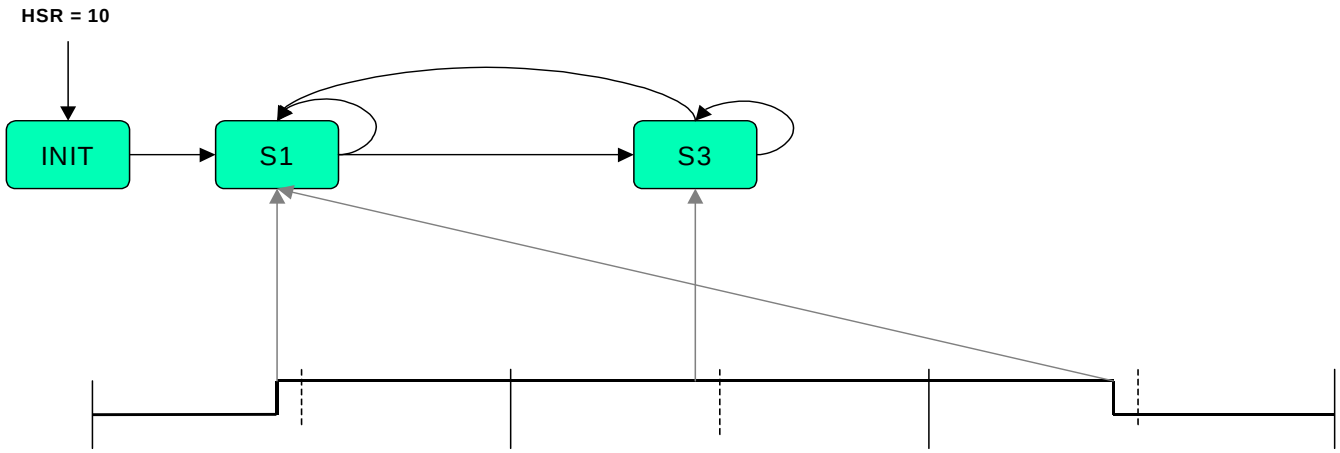

Figure 11. svmStd3Xor_res state diagram

Fault Input for Standard Space Vector Modulation – 3 outputs version – XOR version (svmStd3Xor_fault)

The svmStd3Xor_fault is an input TPU function that monitors the pin, and if a high to low transition occurs, immediately sets all PWM channels low and cancels all further transitions on them. The PWM channels, as well as the synchronization and resolver reference signal channels (if used), have to be initialized again to start them running.

The function returns the actual pinstate as a value of 0 (low) or 1 (high) in the parameter *fault_pinstate*. The parameter is placed on the A1 channel to keep the fault channel parameter space free.

Host Interface

Written By CPU

Written by both CPU and TPU

Written By TPU

Not Used

Table 18. svmStd3Xor_fault Control Bits

Name	Options
3 2 1 0 Channel Function Select	svmStd3Xor_fault function number (Assigned during assembly the DPTRAM code from library TPU functions)
1 0 Channel Priority	00 – Channel Disabled 01 – Low Priority 10 – Middle Priority 11 – High Priority
1 0 Host Service Bits (HSR)	00 – No Host Service Request 01 – Not used 10 – Initialization 11 – Not used
1 0 Host Sequence Bits (HSQ)	xx – Not used
0 Channel Interrupt Enable	0 – Channel Interrupt Disabled 1 – Channel Interrupt Enabled
0 Channel Interrupt Status	0 – Interrupt Not Asserted 1 – Interrupt Asserted

TPU function svmStd3Xor_fault generates an interrupt when a high to low transition appears.

Table 19. svmStd3Xor_fault Parameter RAM

Channel	Parameter	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Fault input	0																
	1																
	2																
	3																
	4																
	5																
	6																
	7																

Table 20. svmStd3Xor_fault parameter description

Parameter	Format	Description
Parameters written by TPU		
fault_pinstate	0 or 1	State of fault pin: 0 ... low 1 ... high

Performance

Table 21. svmStd3Xor_fault State Statistics

State	Max IMB Clock Cycles	RAM Accesses by TPU
INIT	8	2
FAULT	88	5
NO_FAULT	4	1

NOTE: *Execution times do not include the time slot transition time (TST = 10 or 14 IMB clocks*

)

Figure 12. svmStd3Xor_fault timing.

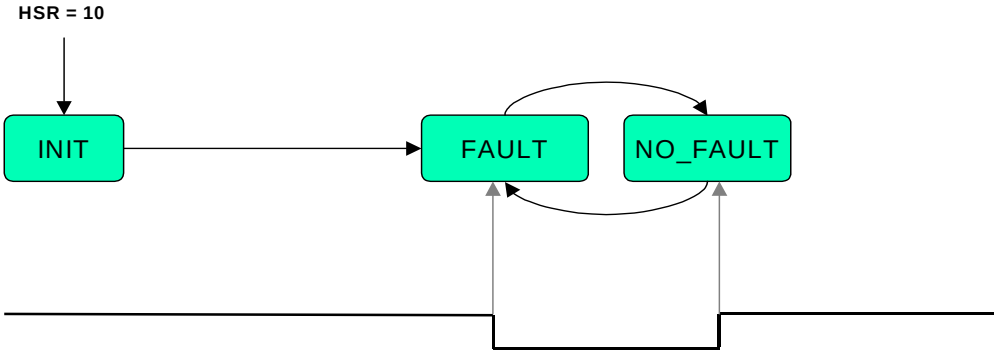

Figure 13. svmStd3Xor_fault state diagram

[redacted]

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