Generation of PWM Schemes for Power Electronic Converters

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***Abstract*-- Advanced Digital Signal Processors (DSP) have the capability to generate complex Pulse Width Modulation (PWM) signals for power electronics converter applications. Floating point processors like DS-1104, FPGA Spartan 6 are popular because of their capability of solving complex mathematics and MATLAB integration feature. But owing to larger space and higher cost requirement these processors can't be used as embedded processor. In this article low cost floating point DSP processor TMS320F28379D is tested for generating complex PWM signals. The result shows generation of PWM is easier and can be adopted for designing power electronics converters.**

***Index Terms*—Pulse Width Modulation (PWM), DSP, Duty Ratio (D).**

I. Introduction

Pulse Width Modulation (PWM) is a control technique used in power electronics converter to regulate power supplied from power source to load. Duty cycle is the output variable of PWM which carries information and encode the control function of converter [1-2]. In many applications where constant energy is to be supplied to load and output voltage is constant like switched mode power converter constant duty cycle fixed frequency PWM signal is required for control. This PWM signal generation can be done in analog domain or in digital domain. In analog domain Op-Amp circuits are extensively used for generating PWM from carrier and modulating signals [2]. But due to component aging, temperature drift and new hardware design for slight variation is restricted the use of analog domain for generating PWM signals. Whereas in digital control generating PWM signal is quite easy and writing programme can change the control signal pattern effectively. Advanced algorithm implementation is relatively easy and faster in digital domain [3]-[8]. Thus application of microcontroller and digital signal processors (DSP) are increasing both in power electronics converter control and power system protection. Digital pulse width modulation schemes are classified into two broad categories i.e. DC-DC converter PWM and Inverter PWM. In DC to DC converter fixed frequency fixed duty cycle PWM is mostly used for open loop configurations. These are typically 20 kHz-100 kHz application. But this frequency range is not limited as with the advancement of power semiconductor technology like SiC, GaN, frequency may increase beyond 100 kHz to achieve high power density operation [9].

For inverter, like Z-source, A-source, multilevel inverter requires complex switching PWM for successful operation for open loop as well as closed loop. Sin-triangle PWM and Space Vector PWM technique is widely used for controlling complex inverter topologies [10-11]. Again, for closed loop control to implement complex algorithm like sliding mode control, adaptive hysteresis control, model predictive control, variable duty and constant frequency operation is required where floating point DS-1104 or Spartan 6 FPGA is used for easy prototype demonstration. DS-1104 is also having MATLAB integration feature thus creating digital control very easy. But for practical implementation this solution can't be realized for embedded system design and prototype making with increased cost and size.

This paper discusses the use of low cost Delfino TMS320F28379D development board-a dual CPU floating point DSP processor [11], for generating complex PWM signal commonly used in power electronics converters.

II. Generation Of PWM Schemes

In an embedded application [13], the target processor produces pulses from a Time Based Clock (TBCLK). The Time Based Clock can run at the CPU speed or a fraction of it. Pulses produced by the TBCLK are counted as they occur forming a staircase signal whose count value at any time is monitored by a Time Based Counter (TBCTR). When the TBCTR reaches a preset value named the Time Base Period (TBPRD), the counter resets itself to 0 and the staircase signal repeats. PWM signals are generated based when the TBCTR equals a Compare (CMP) value as shown in Fig.1.

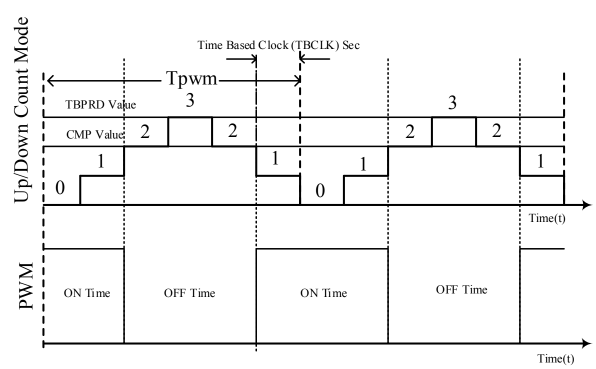

Fig. 1. PWM generation with Up/Down counter using on board oscillator.

The generated frequency of the PWM signal is $F_{sw} = 1/T_{PWM}$.
T_{PWM}=2*TBPRD*TBCLK.
In the stair case each step is termed as one tick. Thus total step in

counter multiplied by each tick time period is total PWM time period. It is also called carrier time period.

Similarly for up count and down count the PWM time period is, (TBPRD+1)*TBCLK.

The resolution, of a PWM generator is equal to the number of Time Based n pulses present in the PWM period expressed as a number of bits. Resolution expressed as a number of bits:

$n=\log_2^{\frac{T_{PWM}}{TBCLK}}$, Number of Time Base pulses per PWM period is $\frac{T_{PWM}}{TBCLK}$. For example, a 20 kHz PWM signal is to be generated using an 80MHz CPU. The Time Based Clock (TBCLK) is set to 1/80Mhz and the resolution is calculated as: Tpwm/TBCLK=(1/20k)/(1/80M) and $n=\log_2(4000)$ =11.96 =12 bits.

The High Resolution Timer option, based on the availability on hardware, decreases the TBCLK to a value of 150^{e-12} seconds. This is particularly useful if your application requires a high PWM frequency

(NOTE: 250 kHz and greater is considered to be a high PWM frequency).

This concept is utilized to generate PWM for buck, boost or synchronous buck, boost converter as shown in Fig. 2 and Fig. 3.

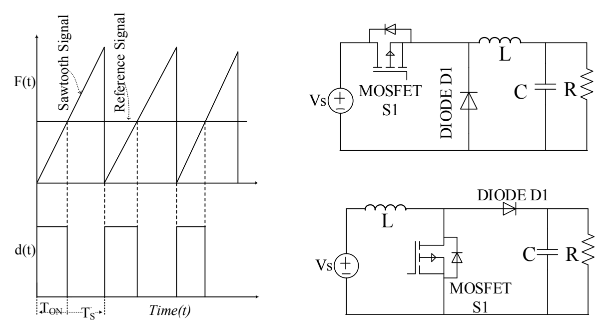

Fig. 2 Fixed Duty (d) PWM for Buck and Boost Converter.

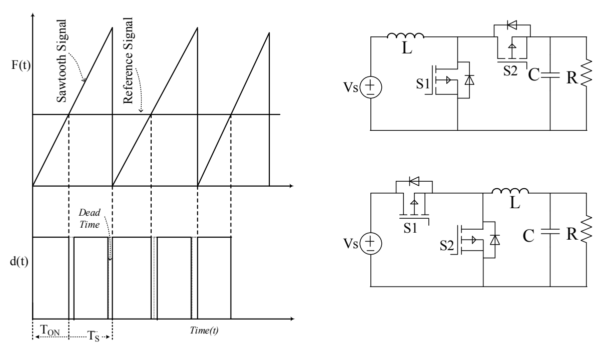

Fig. 3. PWM signal for synchronous buck and boost converter.

Generally PWM time period is the same as the carrier time period. Thus generating high frequency PWM requires same high frequency as carrier. $f_{sw}=f_{carrier}$. Sometime it is difficult in practical circuit to use high carrier frequency. It is possible to increase switching frequency without increasing carrier frequency. For example in the Fig. 4 the triangle wave is compared with two reference value i.e. 0.25 as lower and 0.75 as upper for a triangle peak at 1. Thus two PWM signal is generated as the same time period as triangle time period (f_1, f_2). After XOR operation of f_1 and f_2 i.e. $f = f_1 \oplus f_2$ the output PWM signal is double than carrier triangle signal. Therefore, $f_{sw}=2f_{triangle}$ is possible. For this example the duty ratio is 0.5. The same procedure can be followed to generate dead time intelligently.

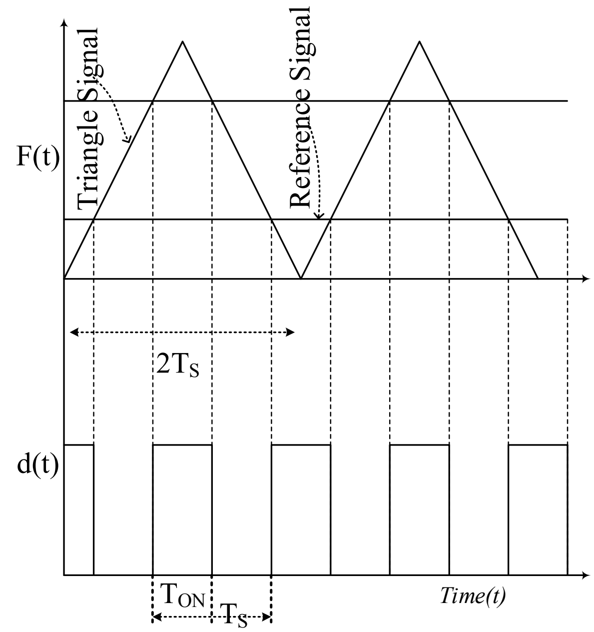

Fig. 4. Generating fixed duty (d) double switching frequency PWM signal form half carrier frequency.

The main interrupt loop coding in DSP for XOR time interrupt operation is

```
    {
  if
  ((((int)(( _out_1  * 3.0517578125e-
005)<0.25))^((int)(((CGDOUBLE) _out_56 )>0.75))))

     {GPBSET = 0x4L;}
    Else
     {GPBCLEAR = 0x4L;};
    _delayOutBuf57 =  t80;
    _delayOutBuf2 =  t25;
    if ( t12)
     _sampBuf21 =  t22;
    if ( t67)
     _sampBuf76 =  t77;
 End Of Sample Count = TIMER2TIM;
}
```

Hardware dead time generation is not flexible but in DSP software approach changing in programming can effectively introduce dead time. Other complex algorithm for inverter control as discussed earlier can be easily done in TMS320F28379D development board. EPWM channels can be effectively utilized for high resolution PWM generation. Simple digital input/output can be programmed for PWM with limited switching frequency typically 2-5 kHz in this board.

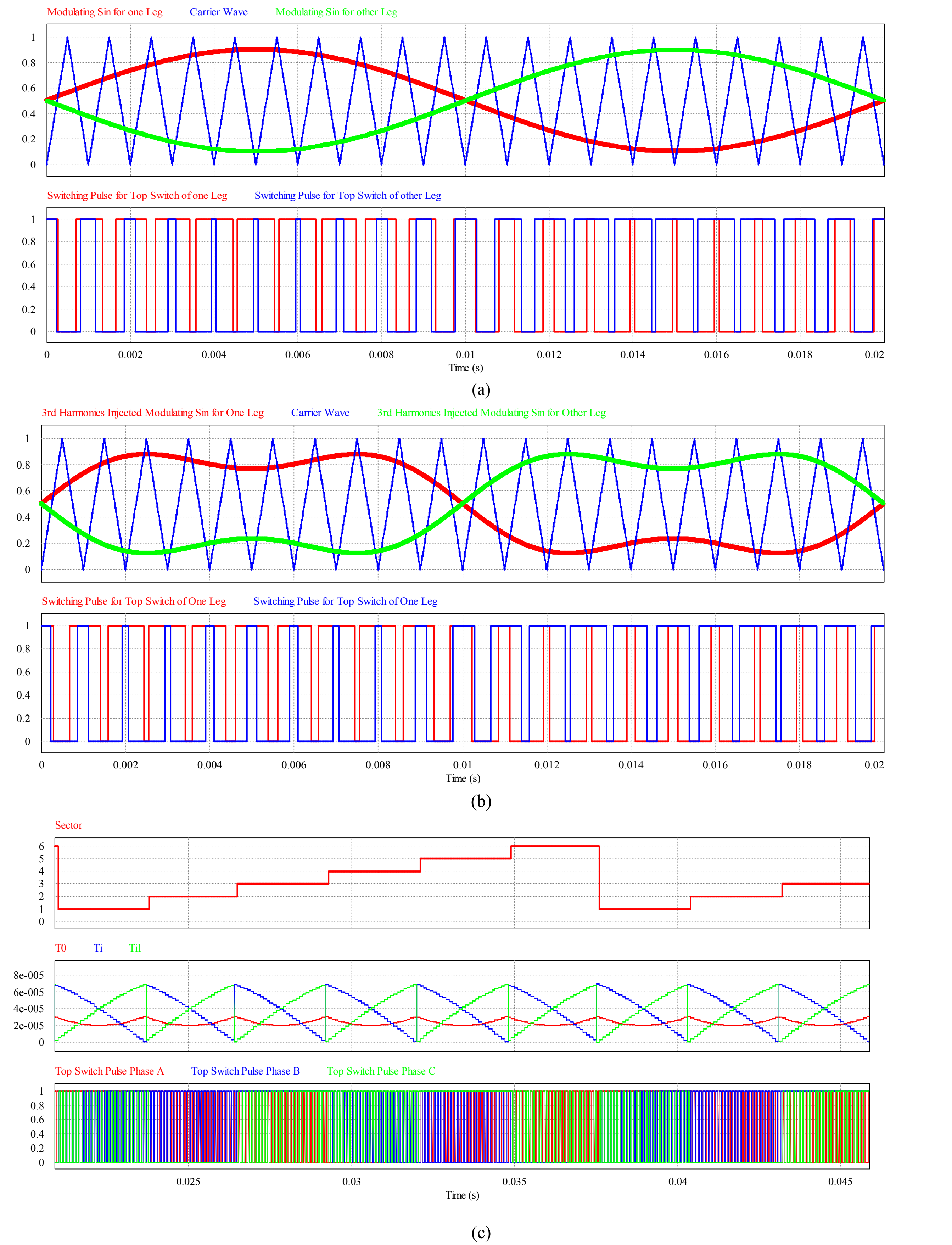

Fig. 5. Inverter Switching Pulse Generation Scheme: (a) Sin-Triangle PWM (1KHz) Generation Scheme for Single phase inverter (b) Third harmonics injected Sin-Triangle PWM (1KHz) for single phase inverter (c) Space vector PWM (10 KHz) for three phase inverter.

The LAUNCHXL-F28379D is a C2000 Delfino MCU F28379D launchpad development kit. This Launchpad C2000 development board has TMS320F28379D MCU which provides 800MIPS of total system performance between dual 200MHz C28x CPUs and dual 200MHz real time control co-processors (CLA). This microcontroller contains 1MB of on-board flash and includes highly differentiated peripherals such as 16bit/12bit ADCs, comparators, 12bit DACs, delta sigma sinc filters, HRPWMs, eCAPs, eQEPs, CANs and more. The Launchpad development kit supports 12bit ADC mode through the header pins and 16bit mode can be driven with external differential signals.

A typical connection to access e_{pwm} channel for port A is pin P_{16} for positive and P_{56} to ground pin. CRO probe cab be connected to this pin to check digital pulse of 3.3-5 volt before use. +5V external power supply is required to F28379D development board after flashing the programme to RAM to work independently. Hardware in loop in also possible with CAN support in this development board. Code composer studio (CCStudio) of Texas instrument is used as a software package to write and download the programme. of Main body of code is written after initialization. For simplicity Sin-Triangle PWM main programme [12] after initialization of timer and global variable is,

```
void main ()
{
  EALLOW;
  CLKCTL &= ~CLK_INTOSC1OFF;
  CLKCTL &= ~CLK_OSCCLKSRCSEL;
  CLKCTL |= CLK_INTOSC2OFF
|CLK_XTALOSCOFF|CLK_XCLKINOFF;
  PLLSTS = 0x10;
  WDCR=0x00ef;
  asm("   clrc DBGM");
  if (!(PLLSTS&8))
    { PLLSTS = 0x40;
      PLLSTS = 0x100;
      PLLCR = 0x10;
    }
  PCLKCR3 = 0x400;
  EDIS;
 simInit( 0 );
  EALLOW;
  GPADIR = 0x80000;
  EDIS;
  startSimDsp();
  installInterruptVec(-2,7,&cgMain);
  TIMER2PRD = 0x1f40;
  TIMER2PRDH = 0x0;
  TIMER2TCR |= 0x4020;
  EALLOW;
  PIECTRL = 1;
  EDIS;
  IER |= 0x2000;
  resetInterrupts();
  enable_interrupts();
  EALLOW;
  PCLKCR0 |= 0x4;
  EDIS;
  dspWaitStandAlone();
}
```

Again with 3rd harmonics injection based sin-triangle PWM the main loop initialization is important. Main programme is same as sin-triangle PWM,

```
 static int __sum_13;
static SIM_STATE tSim={0,0,0
,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,0};
SIM_STATE *sim=&tSim;
static INTERRUPT void cgMain()
{
static int _delayOutBuf9=0;
  int t18; int t19; int t29;
static int _sampBuf28=0;
  int t32;
static CGDOUBLE _cnt50=199;
static CGDOUBLE _cnt58=66;
  CGDOUBLE t61;
  int _out_8; int t1;
  __sum_13 = ( _delayOutBuf9+( _sampBuf28?-
6553:6553));
t18 = ( __sum_13 <6553);
t19 = (((int) t18)|((int)( __sum_13 >32440 /*
0.99@fx1.16 */)));
t29 = !((int) _sampBuf28);
t32 = ( t18?0 /* 0@fx1.16 */: __sum_13 );
t61 = (((((double)sin((++_cnt50 >
199?_cnt50=0:_cnt50)
*0.0314159265358979)*0.8)+1.)*0.5)
+((double)sin((++_cnt58 > 66?_cnt58=0:_cnt58)
*0.0937788851817849)*0.13333));
  _out_8 =  _delayOutBuf9;
 t1 = ( t61>( _out_8  * 3.0517578125e-005));
 if ( t1)
    {GPASET = 0x80000L;}
  else
    {GPACLEAR = 0x80000L;};

  _delayOutBuf9 =  t32;
  if ( t19)
    _sampBuf28 =  t29;
  End Of Sample Count = TIMER2TIM;

}
```

III. CASE STUDIES WITH TMS320F28379D

Fig. 6. (a) Fixed duty constant frequency PWM signal generation (simulated) (b) Fixed duty constant frequency PWM signal generation (practical) (c) Triangular carrier frequency of 500 Hz (simulated) (d) Fixed duty 1Khz frequency PWM signal generation from half carrier frequency i.e. 500Hz. (e) Sin-Triangle PWM generation (Simulated-M-0.8) (f) Sin-Triangle PWM of 1khz switching frequency (Practical-M-0.8)) (g) Space Vector PWM generation for 1kHz switching frequency (Simulated-M-0.8) (h) Space Vector PWM generation for 1kHz switching frequency (Practical-M-0.8). (i) Small increase in duty ratio near zero crossing for space vector PWM (j) Duty ratio changes sinusoidally near zero crossing for Sin-Triangle PWM. (k) Sin-Triangle PWM of 1 kHz switching frequency (practical-M-0.75).

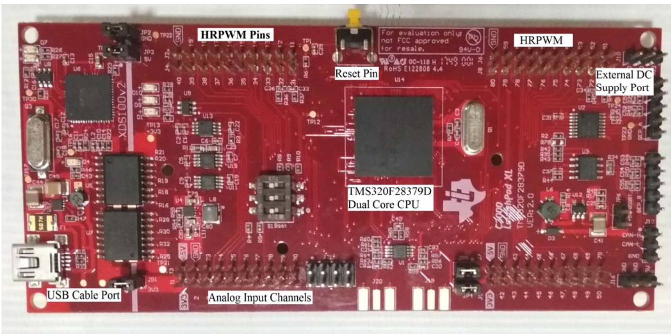

Fig.7. C2000 TMS320F28379D Delfino floating point Development Board.

The low cost development board on TMS320F28379D is shown in Fig. 7. The cost comparision with other floating point processor with this PWM generation capability is shown in Table I.

Table I
Cost Comparision with other Floating Pont Processor

Model	DS 1104	Spartan 6	TMS320F28379D
Cost in $	$3731.00	$695	$34
On board Oscillator Frequency	250MHz with 80ns resolution	240 MHz with 50 ns resolutiin	200 MHz with 150 ps edge control for 16 HRPWM.

From the comparative study with different microcontroller development board as shown in Table-I, it is evident that TMS320F28379D is low cost and effective with 200MHz dual core CPU. The capability of this development board is sown in Fig. 6 where different classical PWM for inverter control is effectively generated.

IV. CONCLUSION

In this paper the effectiveness of the low cost DSP development board is discussed to generate some basic and advanced PWM for power electronics converter control. For practical power electronics embedded system design at low cost the use of this low cost DSP can reduce the overall converter cost. The capability to control advanced mathematics which is required many time for generating PWM for power electronics converter can be handled very easily with DSP TMS320F28379D. This paper also discusses some important aspects of programming DSP to generate PWM for power electronics converter.

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