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BLDC Motor Drives with A Programmable Simplified C-Block to Generate Accurate Six-Step PWM Based on STM32 Microcontroller

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ABSTRACT

This paper presents a digital implementation of a brushless direct current motor (BLDCM) drive with a six-step pulse width modulation (PWM) using a programmable simplified C-block based on the STM32 microcontroller. The implementation is conducted through the PSIM simulation platform, which is commonly used for power electronics and motor control. This approach combines the benefits of using a programmable simplified C-block for precise and flexible programming with the PWM concepts of the STM32 microcontroller. The PWM method used on the BLDCM drive is the unipolar upper PWM technique (H~PWM_L~ON). The performance of the PWM implementation is analyzed in detail, including the accuracy of the PWM generation using a Fast Fourier Transform (FFT), the gating of the IGBTs in the three-phase inverter, and the effect of the duty cycle on the BLDCM's speed, phase voltage, and phase current.

Keywords: BLDCM, microcontroller STM32, PSIM, simplified C-Block, six-step commutation.

INTRODUCTION

The implementation of embedded BLDCM drives using a microcontroller has been carried out in several types of research and products for various applications. The microcontroller is used because it has several advantages, including faster speed, low cost, small chip size, and ease of troubleshooting [1]. Some of the work done using microcontrollers such as Texas Instruments as in [2][3], ATMega as in [1][4][5][6], Microchip as in [7][8], and STM32 as in [9][10]. The type of microcontroller that is popular and used around the world is STMicroelectronics which uses an ARM architecture such as based on STM32. STM32 uses the C-code programming language by offering a large workable portfolio and good digital signal processing capabilities [9][11].

Typical BLDCM drives require a three-phase inverter which plays an important role in controlling power flow. The working principle is that each phase of the motor is energized in 120° electrical intervals based on the position of the rotor (sector). This drive principle is often known as a six-step commutation [12]. Based on the modulation technique, BLDCM is divided into Pulse Amplitude Modulation (PAM) and Pulse Width Modulation (PWM). PWM techniques are divided into two, unipolar and bipolar [13]. In the unipolar technique, the PWM signal is controlled to one phase and the other phase is kept ON. Because only one phase is switched, switching losses from the inverter can be reduced and this technique is considered more widely used in BLDCM drives with PWM techniques [14]. H~PWM_L~ON, H~ON_L~PWM, H or L PWM-ON-PWM, H or L ON-PWM, and H or L PWM-ON is popular techniques of unipolar [15], [16]. While in the bipolar PWM technique both sides of the inverter H and L are controlled via PWM or often called H~PWM_L~PWM [17]. One of the unipolar PWM methods that is often implemented is H~PWM_L~ON with the consideration that this method is one of the PWM methods that substantially has the smallest switching torque ripple [10], [15], [17].

One of the platforms that can be used to implement digital BLDCM drives is PSIM.

PSIM is a simulation software product from Powersim Inc., specifically designed for power electronics and motor control. It is used for power converter analysis, control loop design, and motor drive studies. PSIM is very popular and widely used because it is simple, user-friendly, accurate, and can be developed into real system applications. It can also be integrated with programming facilities using a programmable simplified C-block [18]–[21]. To simulate PWM in PSIM, the 'Gating Block' component or a PWM generator composed of a DC source and a triangular source inserted into a comparator can generally be used. However, these two methods do not represent a PWM generator based on the STM32 microcontroller.

METHODS

Based on the explanations reviewed, this paper proposes a digital implementation of a six-step PWM BLDCM drives with a programmable simplified C-block to generate accurate six-step PWM based on microcontroller STM32 through the PSIM platform which is discussed in detail. The PWM method on BLDCM drives used the unipolar upper PWM technique (H~PWM_L~ON). The discussion was carried out in detail on six-step accurate PWM generation and analyzed the effect of PWM on response performance, including speed, phase voltage, and phase current.

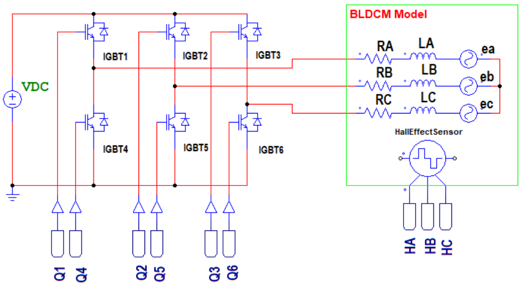


Figure 1. BLDCM with three phase inverter model.

A BLDCM consists of a permanent magnet rotor with 3-phase stator windings, so the drive requires a 3-phase inverter. An overview of how to model his BLDC motor with a three-phase inverter is shown in Figure 1. A position sensor, such as a hall sensor, is required to determine the time of commutation and provide a suitable process for commutation. The position sensor divides the 360° electrical angle into six sectors, one step with two active phases [14].

There are two switching schemes for BLDCM drive with PWM scheme: unipolar and bipolar. In bipolar switching, the PWM signal is applied to all switches in both phases, whereas in unipolar switching only his one switch in one phase goes high (H) or low (L) while the other phase is switched on. Since only one switch receives its PWM signal, unipolar switching has the advantages of lower switching losses and half the current ripple of bipolar switching [14]. For this reason, unipolar PWM is more widely used in BLDCM drives. One of the unipolar PWM methods that is often implemented is H~PWM_L~ON with the consideration that this method is one of the PWM methods that substantially has the smallest switching torque ripple [10], [15], [17]. Thus, this article uses this technique. A summary of the hall effect sensor correlation for the H~PWM_L~ON PWM technique and the 6-sector switching table is shown in Table 1.

Table 1. The six-step commutation with the H~PWM_L~ON table

HA	HB	HC	Sector	Activate IGBT					
				IGBT1	IGBT2	IGBT3	IGBT4	IGBT5	IGBT6
1	1	0	1	PWM	OFF	OFF	OFF	OFF	ON
0	1	0	2	OFF	PWM	OFF	OFF	OFF	ON
0	1	1	3	OFF	PWM	OFF	ON	OFF	OFF
0	0	1	4	OFF	OFF	PWM	ON	OFF	OFF
1	0	1	5	OFF	OFF	PWM	OFF	ON	OFF
1	0	0	6	PWM	OFF	OFF	OFF	ON	OFF

PWM technology is mainly used to adjust the frequency and amplitude of the output voltage of three-phase inverters. The PWM of the inverter can linearly adjust the voltage, frequency, and harmonics of the output voltage. The basic principle of PWM is to generate control pulses from the switching components of a three-phase inverter to produce an output voltage with expected amplitude and frequency values. [22].

In the PSIM 9.1 software platform used in this work, several tools can be used for gating pulse / PWM generators on inverters such as the output of comparing DC value and triangular, Gating Block, Single PWM, 1-Phase PWM, 2-Phase PWM, 3-Phase PWM, Space Vector PWM, PWM General Hardware, Space Vector PWM General Hardware, PWM Pattern Controller [23]. However, from the component or model mentioned above, the PWM generation does not represent the concept of an STM32-based microcontroller. In STM32, PWM is integrated with timers (TIMx). Timer/counter applications can widely use TIMx. TIMx has the same counter against the SysTick timer with additional features including:

- To slow down the timer counting speed, you can use a prescaler
- Can be used as a frequency and PWM programmable output generator
- Can capture the frequency and pulse width of an input signal.
- It can be used as an event counter.
- On a counter overflow, compare match or capture, it can generate interrupts or events.

Each timer embeds a linear clock prescaler which allows you to divide the clock by any integer between 1 and 65536. This allows the counting pace to be precisely adjusted. The auto reload register (ARR) defines the counting period. In down-counting mode, the counter is automatically reloaded with the period value when it underflows. In up-counting mode, the counter rolls over and is reset when it exceeds the auto-reload value [24].

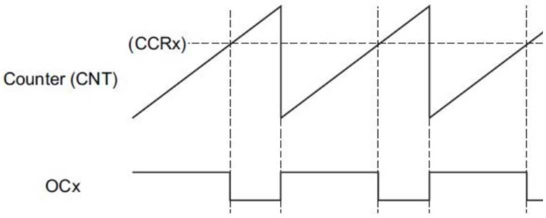
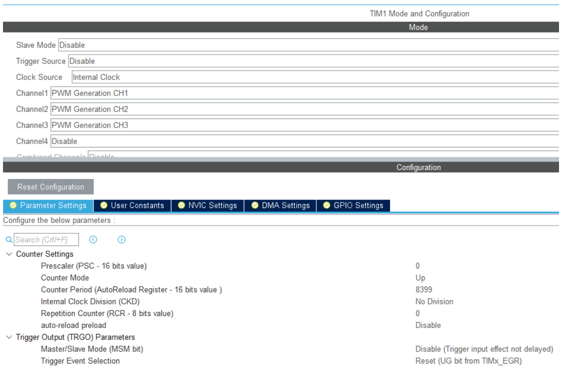


Figure 2. PWM basic principle on STM32.

The basic concepts of PWM signals are constructed by comparing two control signals, they are a carrier signal and a modulation signal. The carrier signal is a triangular waveform generated by counter (CNT). The modulation signal is the DC value generated by CCR. The output of PWM (OCx) is turned on when the counter starts counting from 0. When the counter matches the content of CCRx, OCx output is turned off. When the counter matches ARR, the counter is cleared to 0 and the output is turned on and the counter starts counting up again [25]. This basic concept is depicted in Fig. 2 and an example of how to set the PWM on the STM32 microcontroller via the CubeIDE software can be seen in Fig 3.



Slave Mode Disable
Trigger Source Disable
Clock Source Internal Clock
Channel1 PWM Generation CH1
Channel2 PWM Generation CH2
Channel3 PWM Generation CH3
Channel4 Disable

Configure the below parameters :

Counter Settings
  Prescaler (PSC - 16 bits value) 0
  Counter Mode Up
  Counter Period (AutoReload Register - 16 bits value) 8399
  Internal Clock Division (CKD) No Division
  Repetition Counter (RCR - 8 bits value) 0
  auto-reload preload Disable
Trigger Output (TRGO) Parameters
  Master/Slave Mode (MSM bit) Disable (Trigger input effect not delayed)
  Trigger Event Selection Reset (UG bit from TIMx_EGR)

Figure 3. PWM configuration on STM32.

In using PWM in STM32, there are several stages and formulations. The steps are to determine the frequency of the PWM, frequency timer, and prescaler. Then ARR can be calculated through (1) [26].

$$ARR = \left(\frac{Freq_{Tim}}{Freq_{PWM} \,.\, (Prescaler + 1)}\right) - 1 \quad (1)$$

And if written in simplified C-Block PSIM can be seen below.

```
FreqTim=x1; //in Hz unit
FreqPWM=x2; //in Hz unit
Prescaler=x3;
ARR= (FreqTim/ (FreqPWM*(Prescaler+1)))-1;
y1=ARR;
```

The calculation of the PWM duty cycle is based on a percentage of the ARR value and produces the CCRx value through (2).

$$CCR = \frac{Duty}{100} . ARR \qquad (2)$$

While writing the program in simplified C-block as follows.

```
ARR=x1;
Duty=x2;                  //in %unit
CCRvalue= (Duty/100)*ARR;
y1=CCRvalue;
```

The basic concept of PWM has been described in Fig. 2 where the results of the PWM signal generation depend on the CCR and CNT values when written in simplified C-block as below. The output of this PWM signal will be used in the six-step commutation block to drive a three-phase inverter.

```
Prescaler=x1;
ARR=x2;
CCR=x3;
//**Timer Resolution Calculation /
prescaler output value**-------------
Res++;
if(Res>Prescaler)
{       CNT++;
        Res=0;  }
//------**Triangular generation**----------
-------
if(CNT==ARR)
{       CNT=0;  }
//------**PWM generation 1 channel :
Compare triangular and CCR value**-------
if(CNT<CCR)
{       PWM_Ch1=1;      }
Else
{       PWM_Ch1=0;      }
y1=Res;
y2=CNT;
y3=PWM_Ch1;
```

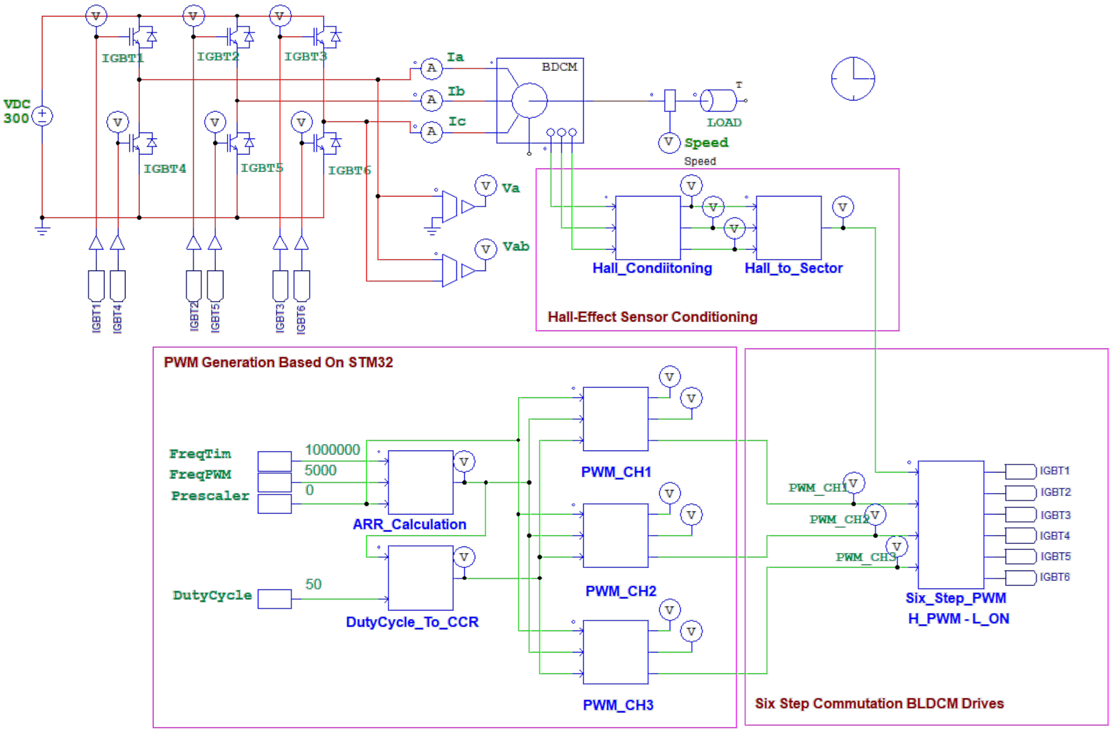


Figure 4. Digital Implementation of BLDCM Drives Using Programmable Simplified C-Block to Generate Accurate Six-Step PWM.

RESULT AND DISCUSSION

Digital Implementation of BLDCM Drives with Six-Step Commutation and STM32-Based PWM Generation in the PSIM platform is shown in Fig. 4. The system consists of a three-phase inverter, BLDCM, block hall-effect sensor conditioning, block STM32-based PWM generation, and block six-step commutation.

In the Simulation Control tool in the PSIM software simulation, the time step unit is in seconds. This time step must also be equal to the FreqTim value in Hz in the PWM generation block. FreqTim is used to determine the Auto Reload Register (ARR) calculation through the C block ARR_Calculation with variable input consisting of frequency timer (FreqTim) in Hz, frequency PWM (FreqPWM) in Hz, and Prescaler. In contrast to the default setting of the STM32 frequency timer, which is 168 MHz or 84 MHz depending on the Advanced Peripheral Bus (APB) signal support, in this case, the FreqTim setting is 1000000 Hz to simplify and speed up the simulation work of the PSIM software.

In this paper, we use a PWM value set of 5 kHz with a Prescaler of 0. The results of the PWM performance are analyzed at a set duty cycle of 75%, 50%, and 25% and can be seen in Fig. 5. For 5 kHz PWM frequency the ARR value from the C-Block ARR_Calculation is 199, then for duty cycle 75%, 50%, and 25% the C-Bock DutyCycle_To_CCR results in the value of 149.25, 99.5, and 49.75 respectively. This calculation result of the CCR value will be used on the C-Block PWM_CH1 to generate a PWM signal.

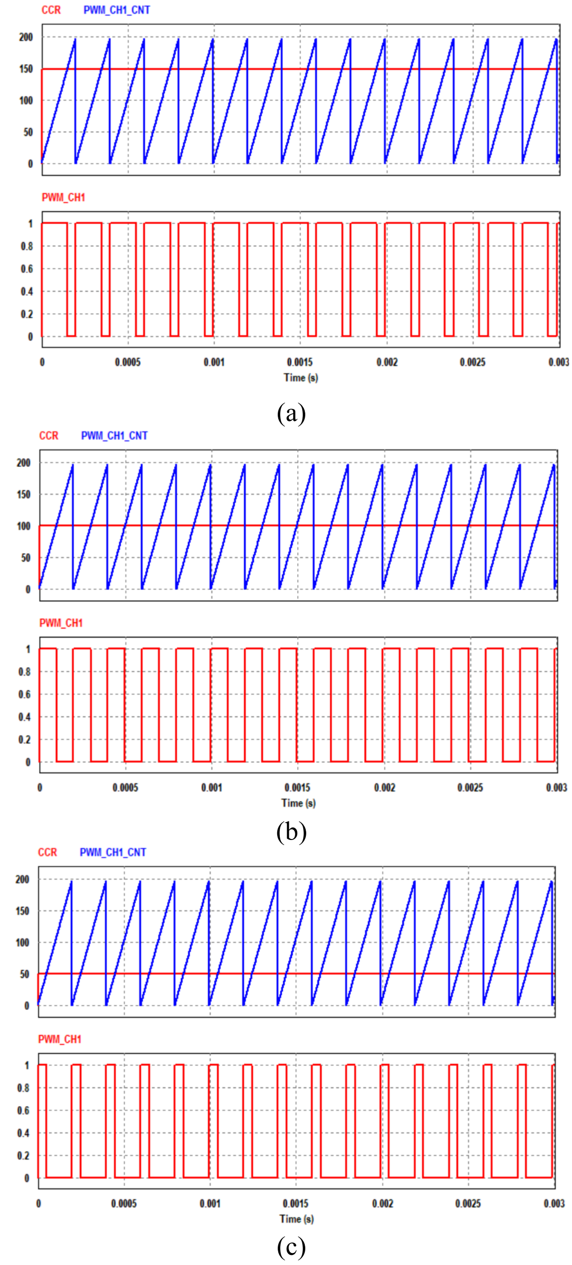


Figure 5. Results of PWM Generator Based on STM32 on PSIM Software

To validate the accurate of the PWM signal that has been generated the frequency is as desired (5kHz), it can be proven by performing the FFT analysis shown in Fig. 6.

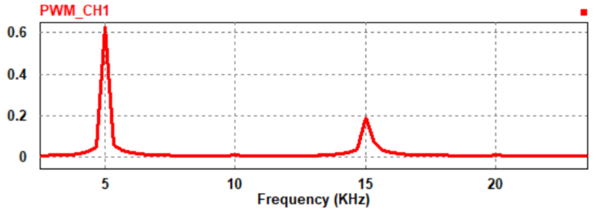


Figure 6. FFT Analysis results from the PWM signal from the block PWM Generator Based on STM32

The next observation is on the IGBT gate signal on a three-phase inverter. In six-step commutation, the signal gating correlated with its sector is shown in Fig. 7. It can be seen that IGBT 1, IGBT 2, and IGBT 3 are high-side IGBT with PWM signal form, while the remaining IGBT are low-side IGBT with ON signal form.

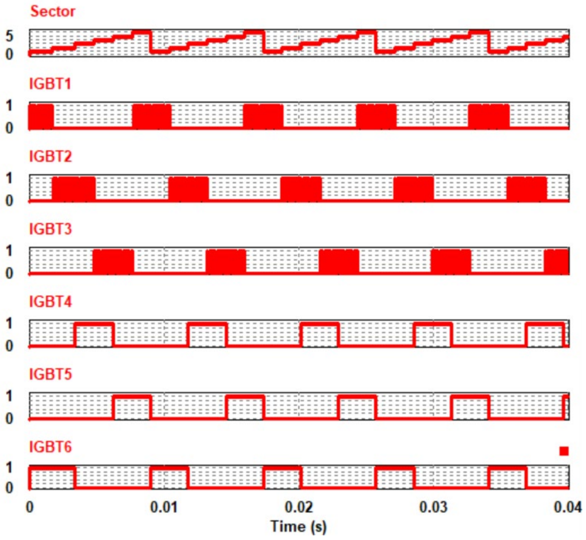
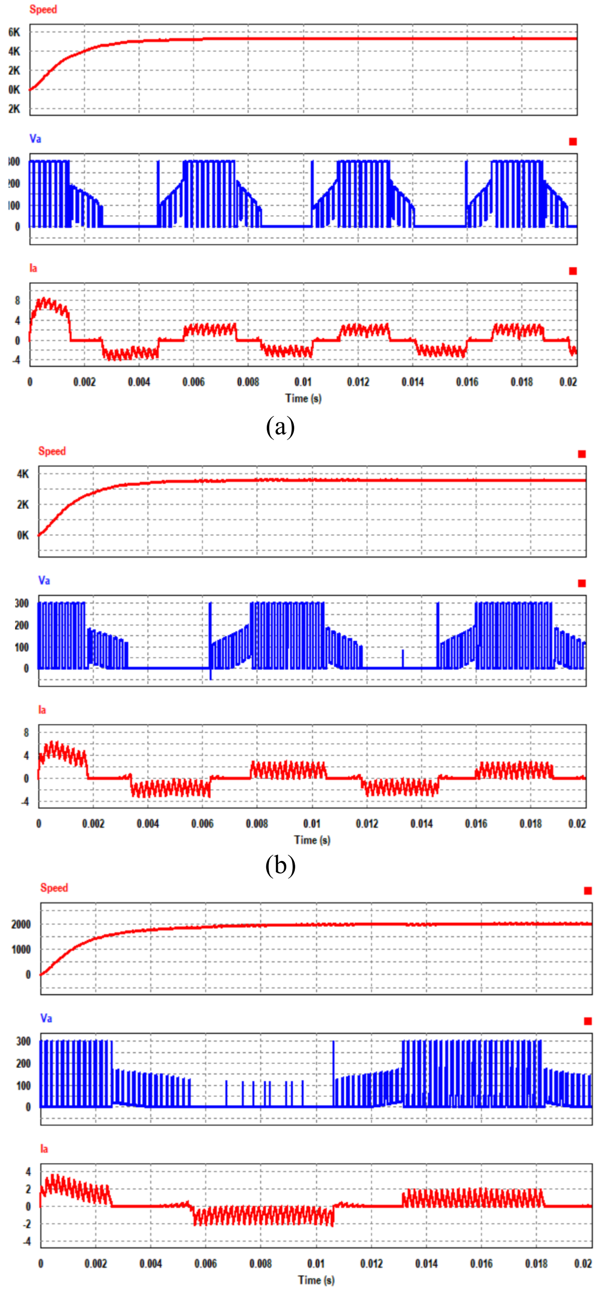


Figure 7. Sector and gating signal on IGBT

On the BLDCM drives, the variation of the duty cycle from the PWM will affect the performance of the BLDCM, including speed, phase voltage, and phase current. The validation of this analysis is shown in Fig. 8 which is applied with a duty cycle variation of 75%, 50%, and 25% with no-load motor conditions. In Fig. 8 (a) 75% duty cycle, the BLDCM speed reaches 5315 rpm with a phase voltage RMS value of 173.86 V and consumes phase current RMS value of 2.52 A. In the next duty cycle of 50%, the BLDCM speed reaches 3585 rpm with a phase voltage RMS value of 144.38 V and consumes phase current RMS value of 1.82 A as in Fig. 8 (b). Fig. 8 (c) with PWM 25% resulted in a BLDCM speed of 2001 rpm with a phase voltage RMS value of 104.91 V and consumes phase current RMS value of 1.03 A.



(a)

(b)

(c)

Figure 8. Speed, phase voltage, and phase current performance with various duty cycles of a three-phase PWM inverter (a) 75% (b) 50% (c) 25%.

CONCLUSION

A digital implementation of a BLDCM drive system with six-step commutation and an STM32-based pulse width modulation (PWM) generation through the PSIM platform was presented. The PWM technique on the BLDCM drive used is the unipolar upper PWM technique (H~PWM_L~ON). The PWM frequency was set at 5 kHz, and the duty cycle was varied at 75%, 50%, and 25%. The PWM signals were analyzed using an FFT to ensure their accuracy, and the gating of the IGBTs in the three-phase inverter was also analyzed. The performance of the BLDCM was then evaluated at different duty cycles, with results showing that the duty cycle affects the BLDCM's speed, phase voltage, and phase current.

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