# The Next Level of Power Conversion with Cortex-M4 based MCUs

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## Abstract

In the power conversion world, the tendency of migrating into digital control loops has been gaining popularity over the last few years. Not only does a digital implementation provide better immunity to process and operating conditions, but it can also increase the resource usage density. With the powerful ARM® processors often found in today's microcontrollers, together with a diversified peripheral arrangement, this type of solution is attractive to control power conversion stages, with a good design reuse factor and reduced overall cost.

Using a microcontroller for power conversion applications may not always be straightforward because of the big effort of mapping previously and newly developed topologies from the pure analog (or power controller) form into a more complex microcontroller system. This paper however will demonstrate how the ARM® Cortex™ M4 CPU of the Infineon XMC4000 product family and the associated peripherals, are tailored to power conversion applications, and how you can take advantage of this to build a design with a better resource density and reduced bill of material.

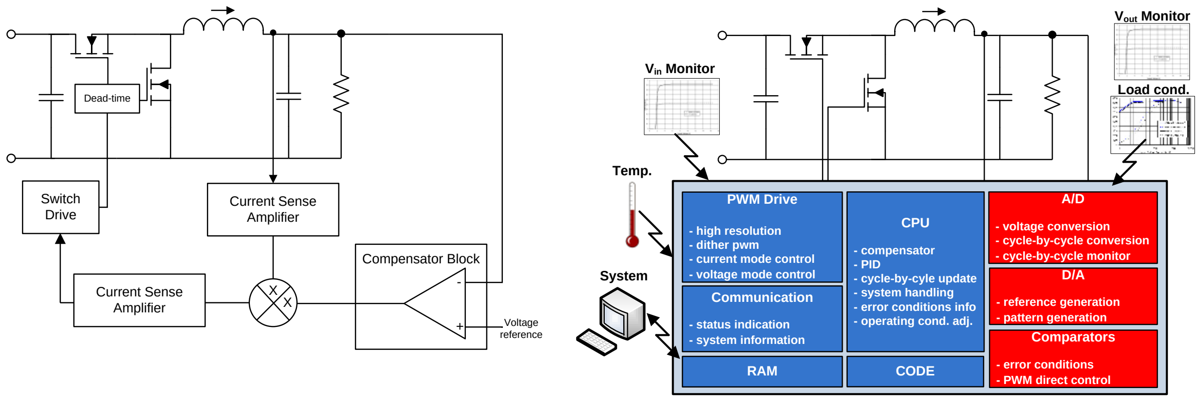

## Introduction

Over the last fifty years, mankind has doubled the world population and tripled average energy consumption. With increases of this magnitude, the paradigm of resources and energy versus the number of consumers is no longer local to developed countries, but global. The world is now in a constant search for resource and energy optimization, with the aim of creating a better and sustainable life for all of us.

Power conversion is a big part in energy usage and distribution optimization. Power conversion engineers are driven into a constant search for improvement of power density and efficiency. A high power density will enable a smaller footprint, while improved efficiency will provide "greener" designs, with a better cost versus energy consumption ratio.

With the aim of optimizing power conversion designs, industry has started the migration of the common analog control to a digital control. Digital control provides better immunity to process variations, and can compensate power stages dependent on several parameters such as different temperatures and operating conditions like load, input or output voltage. Digital control also offers a high level of portability and reliability.

State of the art Infineon microcontrollers, such as the **XMC4000 family**, have a complete set of peripherals that together with the powerful ARM® Cortex™ M4F CPU, can easily perform all the tasks needed to optimize a power conversion stage. The comprehensive set of peripherals can also help lead to an increase of resource density and decrease the manufacturing costs (by for example controlling several power stages, handling communication, monitoring operating conditions, etc.).




a) Analog Implementation

b) MCU Implementation

**Figure 1 – Example of a Power Conversion application control with a microcontroller: a) Typical Analog Implementation; b) MCU implementation**

With most generic MCU solutions, the migration jump from a complete external component solution or an implementation with a power controller is often met with hurdles and problems that are difficult to predict. The Infineon XMC family approach enables a cleaner identification of resources for each and single power conversion application. This includes single power conversion stages such as Buck or Boost Converters, Flyback, Half-Bridge, Resonant converters, but also extends itself to the most complex applications in the market today, such as Interleaved PFC, Phase-Shift Full Bridges, N-Phase Buck Converters, Multi-Level converters, and so on.

With the **Infineon XMC family** of products, you can adjust your MCU resources to your power conversion needs, instead of the targets to be met being constrained by the available resources.

## XMC4000 Microcontroller System

The **XMC4000** devices are built on the powerful **ARM® Cortex™ M4** processor with a Floating Point Unit (FPU), a Memory Protection Unit (MPU) and a Nested Vector Interrupt Controller (NVIC). The communication between the peripherals and the ARM® Cortex™ M4 is based on a multi-layer, multi-master bus system, optimized for real-time applications. The Direct Memory Access (DMA) can be used to perform data transfers from peripheral-to-peripheral, memory-to-peripheral, or peripheral-to-memory. This offloads the processor for the demanding real-time computation tasks.

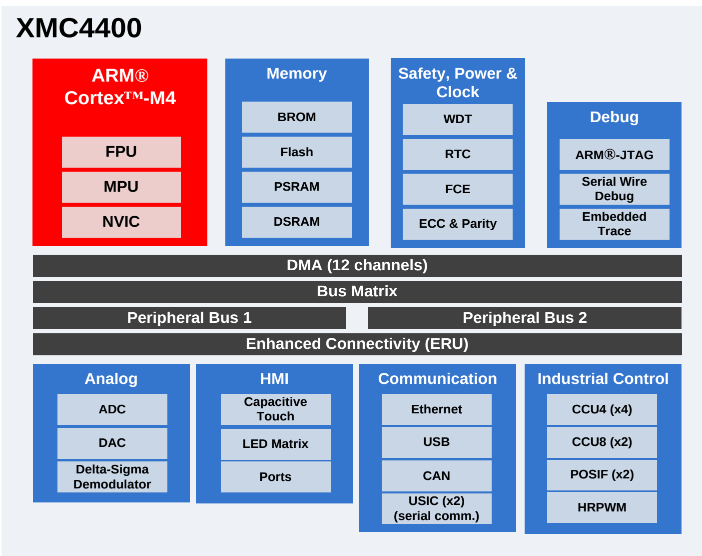



**Figure 2 – XMC4400 Device Diagram**

The peripherals included in the **XMC4000** MCU family contain dedicated features for HMI or Communication applications. The Industrial Control subset contains an extensive list of peripherals especially developed for power conversion and motor control:

- CCU4 and CCU8 for PWM generation and signal conditioning
- POSIF for Motor Control and Multi-Channel PWM control
- HRPWM for High Resolution PWM generation with built-in high speed Comparators and slope generators (for current control applications)

The analog group contains several ADC channels that are able to perform sequential and chained conversions, and offer a fast compare mode for demanding power conversion monitoring. The DAC channels enable fast digital to analog conversion with a dedicated pattern generator.

## Adjust Your MCU to Your Power Conversion Application

In the power conversion world there are several converter topologies and normally two major control loop implementations: current control or voltage control. The converter topology chosen directly dictates the minimum amount of resources that are needed. If for example a synchronous Buck Converter is present in the application, it is a safe assumption that at least two complementary PWM signals and a current and/or voltage sensing loop are needed. The choice between a current or a voltage control loop is normally dictated by how fast the response of the system should be, versus updates on the line or output load.

Already we can see that there are several variables to be considered when choosing a microcontroller for a given power conversion application. If we also add the different modulation schemes that currently exist in the power conversion world (Figure 3), then we have even more resource variables, and these can be interconnected or shared:

- Resources to drive the chosen converter
- Resources for the current or voltage loop
- Resource for controlling the chosen modulation

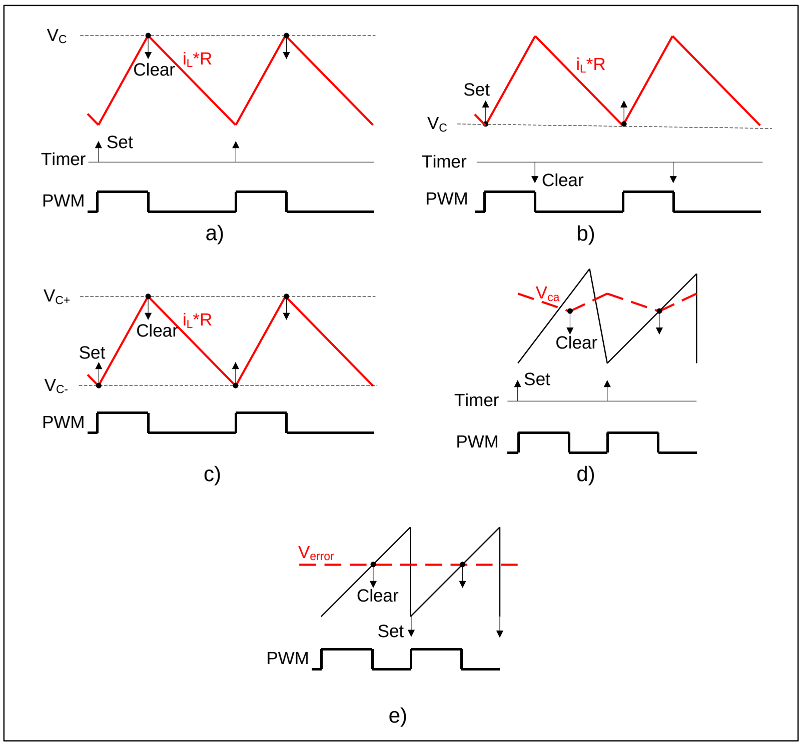


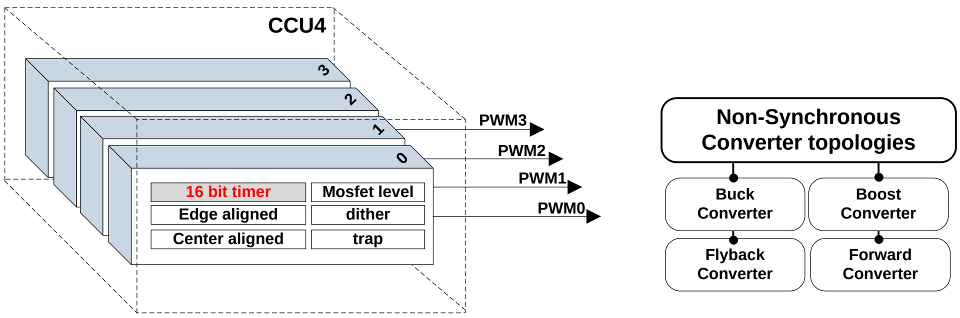

**Figure 3 – Different modulation schemes: a) peak current control; b) valley current control; c) hysteretic control mode; d) average current control mode; e) voltage control mode**

The decision of which microcontroller to take becomes even more complex when several products or derivatives need to be developed (each one of them with different requirements for power conversion).

The resource arrangement of the new XMC4000 microcontrollers gives you the possibility of adjusting the MCU to the specific power conversion needs, reducing the initial complexity of analyzing each single requirement.

### Adjust the XMC4000 resources for driving the converter

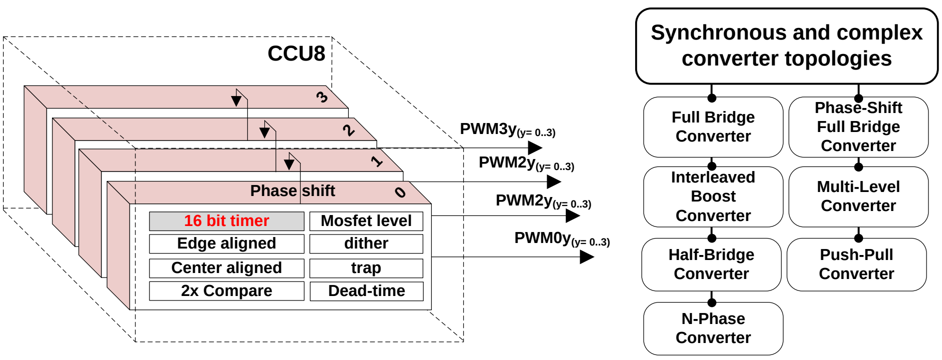
The direct drive resources (PWM) of the power conversion can be taken from the CCU4 (Capture & Compare Unit 4) of the XMC4000 in a straightforward manner if non-synchronous converters are being used (Figure 4). Each CCU4 contains four, sixteen bit timers, with dedicated functions for controlling non-synchronous topologies: select the active level of the switch, over current protection with trap function, dither for increasing the PWM resolution, etc.




- Up to 4 non synchronous converters
- Safe shutdown control
- Resolution boost via dither

**Figure 4 – CCU4 (Capture & Compare Unit 4) resources for generating the PWM**

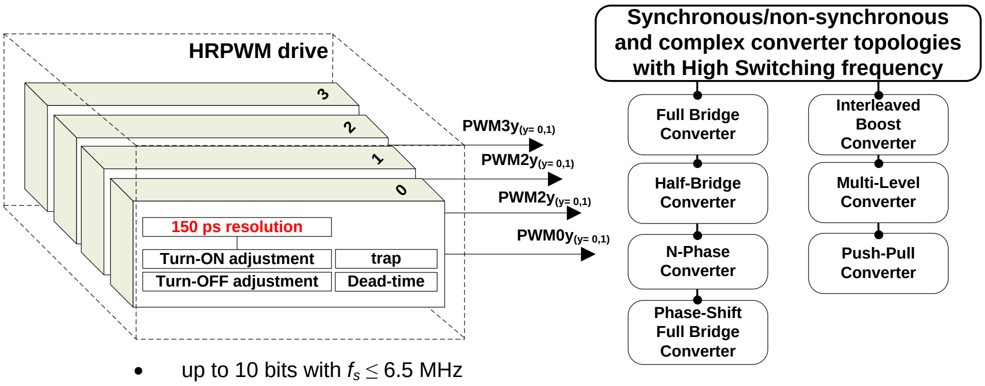
If synchronous converters or more complex topologies are used (like phase shift, interleaved or multi-level conversion), then the CCU8 (Capture & Compare 8) is used for the direct PWM drive. CCU8 contains four identical sixteen bit timers with two compare channels, that are able to generate up to four PWM signals (per Timer Slice) adding up to a maximum of sixteen output PWM signals. Dead-time control for synchronous converters is also built-in (Figure 5).




- Up to 16 PWM outputs
- Programmable dead-time
- Asymmetric PWM mode
- Phase Shift Control

**Figure 5 – CCU8 (Capture & Compare Unit 8) resources for generating the PWM**

To achieve a higher power density and cost ratio in the development of a power conversion application, the switching frequency of the converter should be as high as possible. Increasing the switching frequency will decrease the size of the filtering and coil stages of the power converter, therefore decreasing the cost of these components. It will also decrease the heat dissipation concerns. To address the market of high switching frequency converters, the XMC4000 as one HRPWM (High Resolution PWM) unit can achieve a 10 bit resolution for converters with a switching frequency of up to 6 MHz (Figure 6).




- up to 10 bits with $f_s \leq 6.5$ MHz
- Up to 8 PWM outputs
- Adjustable dead-time
- Phase Shift Control
- 150 ps resolution for duty-cycle
- 150 ps resolution for phase-shift

**Figure 6 – HRPWM resources for generating the PWM**

## Adjust the XMC4000 resources for the converter loop

There are two major control loops for a typical power converter: voltage mode control and current mode control. While the voltage control follows a simpler implementation because it only contains one loop, it has the disadvantage of having a slower response to line or load updates. This will impose a non-favorable transient response. The current control “updates” the voltage control with an additional loop. This loop will sense the circuit current. This control scheme is therefore more complex to implement, but it can compensate for a change of the input voltage or the load before this affects the output voltage of the converter (Figure 7).

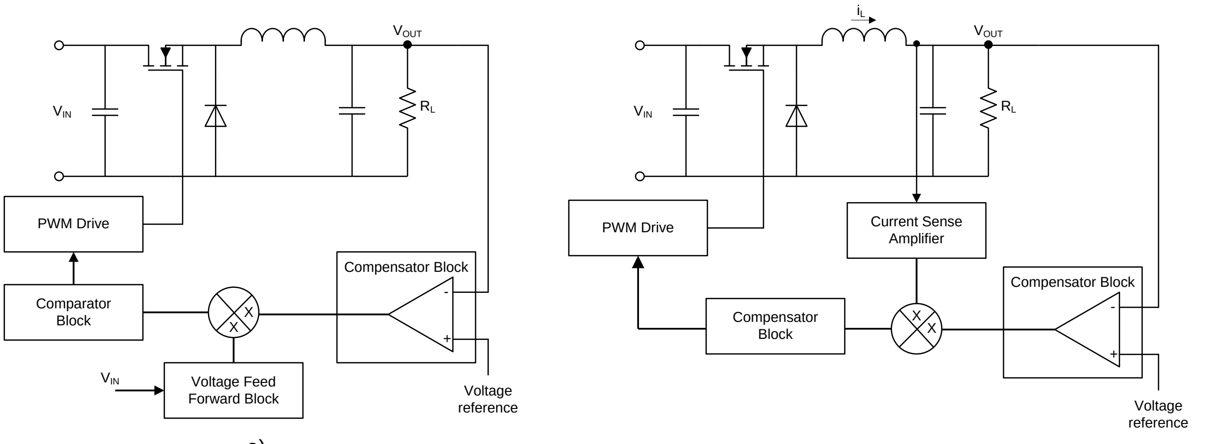



**Figure 7 – Control loops: a) voltage control; b) current control**

It is common to have power conversion applications that follow different control loop implementations (voltage or current). The microcontroller therefore needs to provide proper resource arrangements for both schemes. The **XMC4000** can be used with either of these two schemes, and it can even be used for applications where both schemes need to coexist, so increasing the resource density and decreasing the bill of materials.

The ARM® Cortex™ M4 powerful processor can be used to implement the required compensator blocks used for the voltage or current control modes (Figure 8). This can be done by using the ADC to sense the voltage output and the coil current of the converter.

The ADC results will then be used by the processor to calculate the next cycle PWM values. Because the compensator blocks are implemented digitally, only a small amount of external resources are required. The amount of resources can be limited to some signal accommodation components.

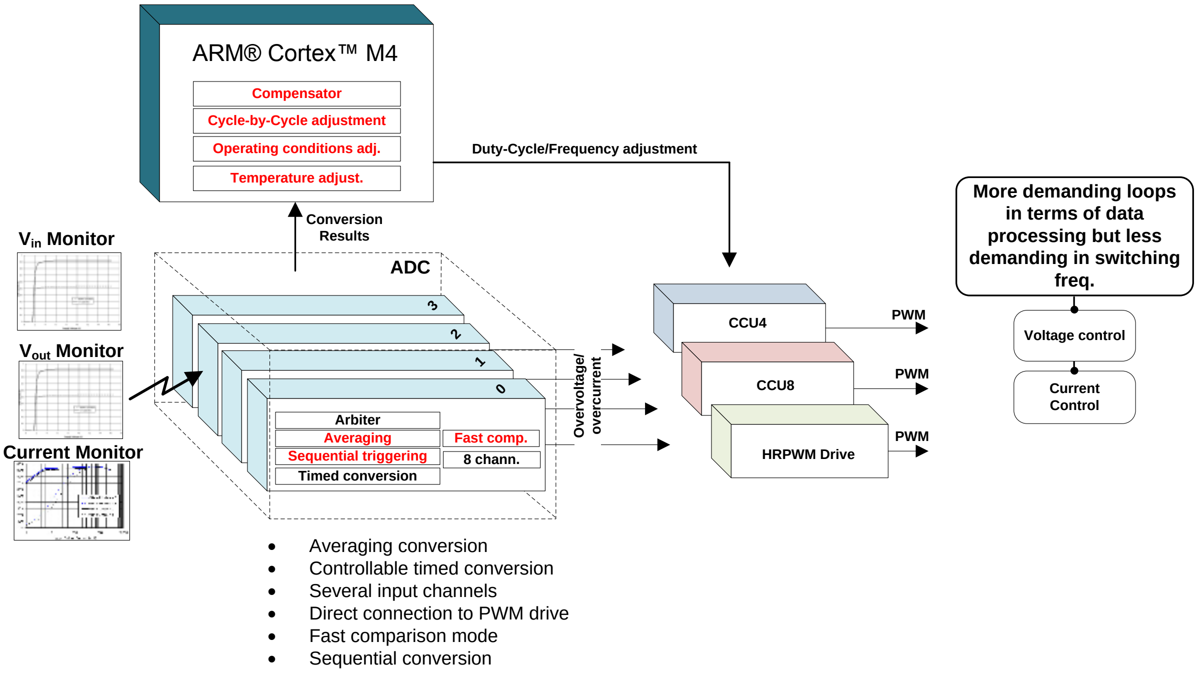



**Figure 8 – ADC and ARM® Cortex™ M4 resources for control loop implementation**

By implementing a loop with an ADC and the CPU, some latency may be incurred, which may not be suitable for high switching frequency converters. As the switching frequency of the converter increases, the acceptable latency for the control loop decreases. This is especially critical for control loops that implement cycle-by-cycle monitoring, such as peak current control, hysteretic control, valley current control, etc.

The HRPWM unit contains a monitor that is tailored for fast control loop implementations (Figure 9). This monitor part contains three dedicated high speed comparators and DACs that enable the cycle-by-cycle current to be monitored for different modulation schemes (peak or valley current control, hysteretic mode up to 5 MHz, etc.), without any CPU interaction. The direct connection to the drive units (CCU4, CCU8 or HRPWM drive part) is implemented such that there is no need for CPU usage.

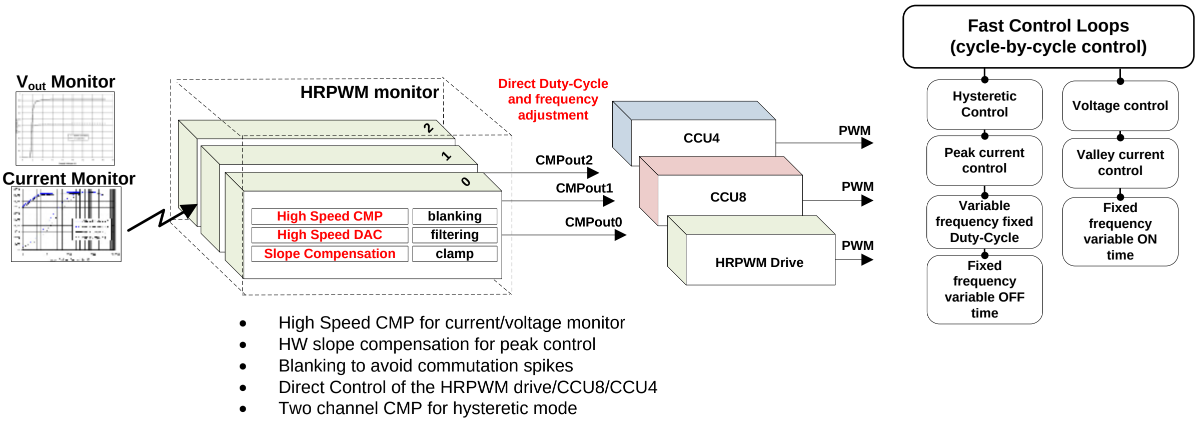



**Figure 9 – HRPWM monitor resources for control loop implementation**

For a resource organization that can cope with any type of power converter topology, control loop or modulation scheme, the XMC4000 solution can be seen in Figure 10. The HRPWM monitor is used for fast control loop implementation, while the ADC and ARM® Cortex™ M4 can handle the slow loops and operating conditions optimization. The CCU4, CCU8 and HRPWM drive units are used to drive the power converter PWM signals.

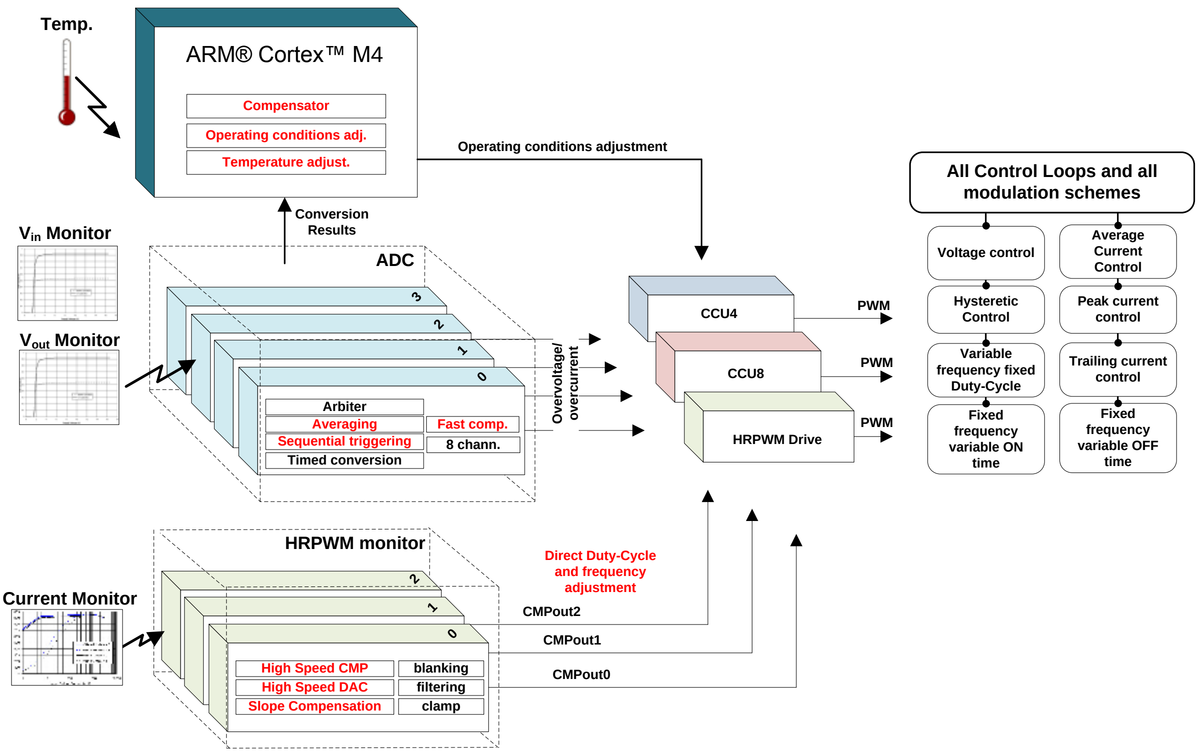



**Figure 10 – XMC4000 resource organization for any type of control loop/power topology**

With the powerful arrangement of resources inside the XMC4000 it is now possible to adjust the microcontroller to the needs of the power conversion stage (topology, control loop and modulation scheme), and at the same time decrease the number of external components.

Figure 11 shows the implementation of a control loop for a synchronous buck converter using peak current control modulation. The resources inside the drive units (HRPWM, CCU4, CCU8) can substitute the following external components: current comparator, slope/ramp generator, the latch generating the PWM and the dead-time driver. The ADC together with the processor routines can substitute the sensing and accommodation of the voltage output (this loop is slower than the current loop handled by the HRPWM).

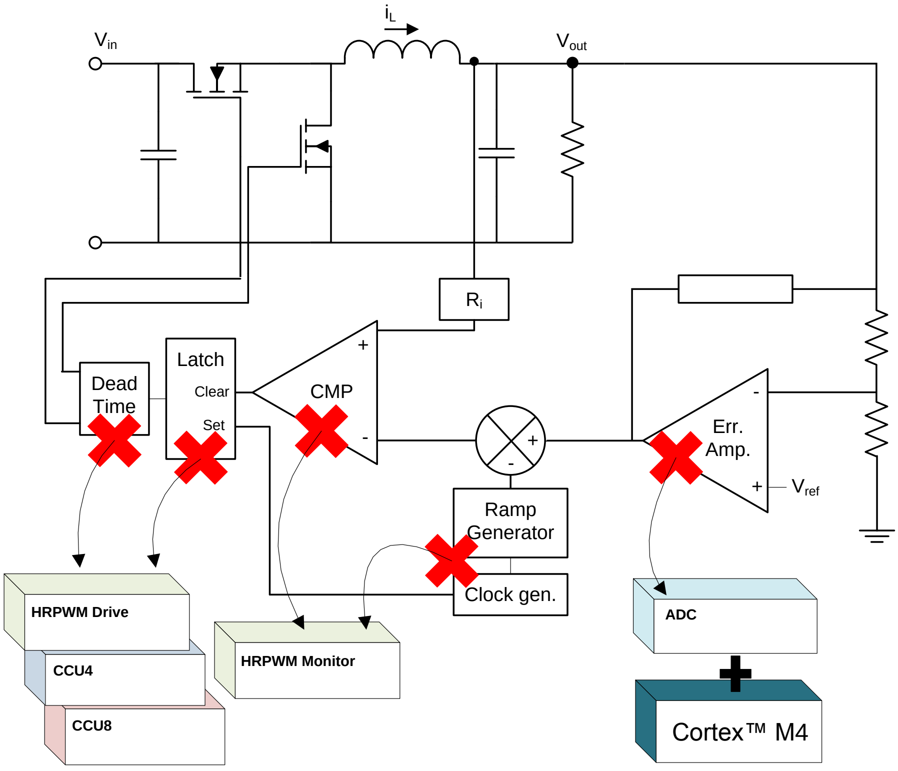



**Figure 11 – Peak Current control with XMC4000**

## Adjusting Your XMC4000 to Your Power Conversion

The XMC4000 is a very powerful microcontroller that can be adjusted to your power conversion topology and control loop. This turns the XMC4000 into a perfect partner for your product line development by covering the entire range of power conversion topologies (Figure 12), reducing porting and feasibility expenses, and increasing cross-derivative compatibility.

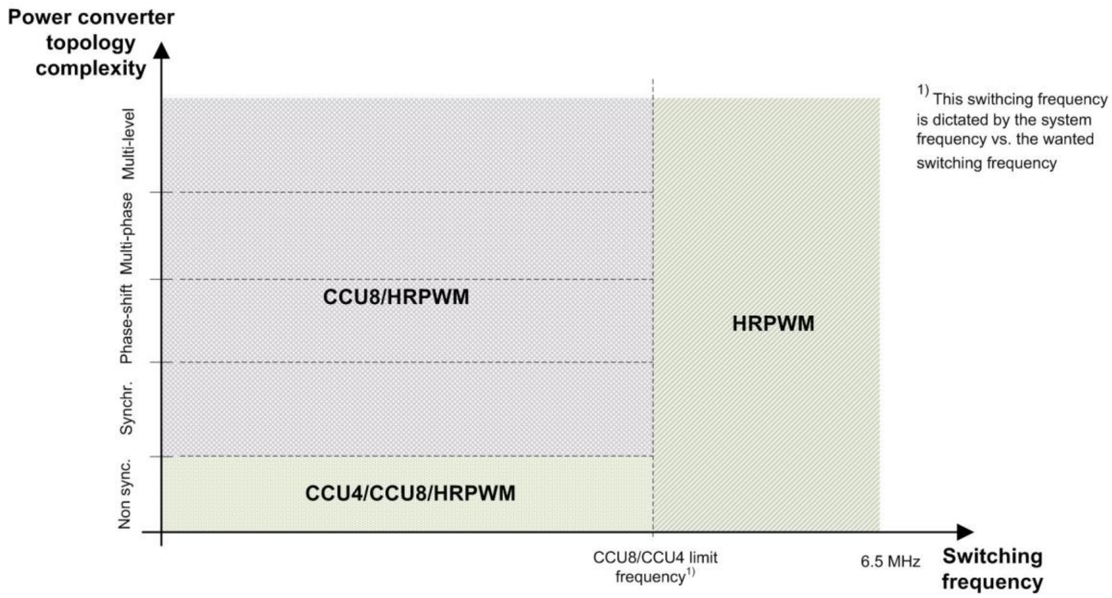



**Figure 12 – Power Converter vs. Resources**

By combining the resources of the XMC4000, the complete set of control loops and modulation schemes can be covered: from the simplest voltage mode control to the most complex current control loop (Figure 13). Using the XMC4000 resource functions tailored for power conversion (e.g. HRPWM, ADC, ARM® Cortex™ M4), the resource density of the final application can be increased by reducing the number of external components, and at the same time reducing the total cost of the product.

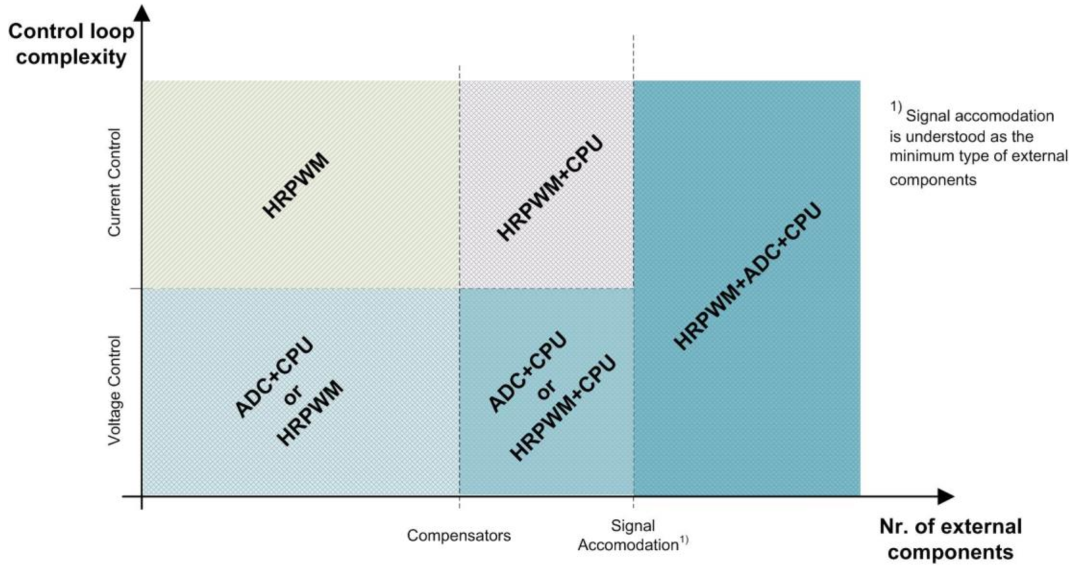



**Figure 13 – Control Loop vs. External Components**

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