# Digital Control in a MicroTCA Power System

Technical Paper 006

First presented at Digital Power Europe 2007

A look at the significant performance enhancements made available by using digitally controlled DC/DC converters in a MicroTCA power system.

## CONTENTS




ABOUT THIS PAPER
Material contained in this document was first presented on November 13, 2007 at Digital Power Europe 2007 – Digital Power Applications session. Digital Power Europe (DPE) is a European-specific, three-day conference that served an international audience of decision makers who are interested in learning about and contributing to the latest practical advancements in digital power control techniques in electronics systems and power converters, along with digital energy management and power management in enterprise-level installations and related digital equipment.


## 1. INTRODUCTION

Micro Telecommunications Computing Architecture (MicroTCA™) is a relatively new architectural specification for Information and Communications Technology (ICT) equipment, intended for relatively small low power applications where it can be more cost effective than other ICT architectures. The key power assembly in MicroTCA is called the "power module". After a brief description of MicroTCA, this paper will address the MicroTCA power module in more detail, with an emphasis on how digital control techniques can enhance its performance. The design of the 12 V DC/DC converter function within the power module will receive particular attention. It will be shown that the output power density and efficiency of the power module can be significantly enhanced by techniques such as paralleling two converters with sophisticated current sharing and synchronization capabilities. It will also be shown that the Power Management Bus (PMBus™) can be an effective tool for communication within the power module.

This paper may serve as a general introduction to MicroTCA power systems for those readers who are knowledgeable about contemporary power system design but are considering their first designs to the MicroTCA specification. It should also be useful for those who are already conversant with MicroTCA but are looking for more information on the details of the power system implementation and choices in the power module design. The design challenges and proposed solutions will in many cases also apply to other more generic products such as Intermediated Bus Converters (IBC) intended for distributed power systems.

## 2. MICROTCA OVERVIEW

MicroTCA, which was ratified by the PCI Industrial Computer Manufacters Group (PICMG™) in July 2006, is the latest generation of open-architecture platforms developed by the PICMG for ICT equipment. It builds upon the heritage of previous architectures and technology such as Advanced Telecommunications Computing Architecture (AdvancedTCA™), maintaining much of the same functionality but with different system partitioning and with optimization to support systems with lower power levels such as Customer Premises Equipment (CPE) and Edge and Access equipment. While smaller and more cost effective than AdvancedTCA, the reliability and availability requirements for MicroTCA systems are typically just as stringent as those for equipment implemented with AdvancedTCA. The same basic functionality in terms of power conditioning and control is also required. One of the main differences between the two architectures is the degree of centralization and the physical partitioning of the power systems.

A typical MicroTCA equipment enclosure is shown in *Figure 1*. MicroTCA systems may be packaged in either 600 mm ETSI enclosures or 19 inch racks, with a 6U height considered a large system. Smaller enclosures are also possible. Most MicroTCA systems operate from -48 V DC telecom power, and this power source will be assumed in the remainder of the paper. +24 V and universal AC line power sources are also possible. Advanced Mezzanine Card (AdvancedMC™) modules are used to package the load electronics. These mezzanine modules are identical to those used with AdvancedTCA carrier-boards, leveraging development costs between the two architectures, providing a migration path and economies of scale for the production of AdvancedMCs. The AdvancedMC modules plug into the upper row of slots in the enclosure shown.

A key feature of the MicroTCA system is the power module, which contains the majority of the power conversion and control circuitry and eliminates the need for the large planar carrier-boards of the AdvancedTCA systems. The power module includes the functions of power filtering, DC/DC conversion, as well as power management. The system shown uses two power modules and they are located at the extreme right and left ends of the upper row of plugged modules. DC input power is plugged to the connectors on the front panel of the power modules, while 12 V and 3.3 V payload and management power is connected to the MicroTCA backplane at the rear of the power modules.

The power module is the focus of this paper and will be described in more detail in the following sections. The reader is referred to references [2] and [5] for more detail about MicroTCA.

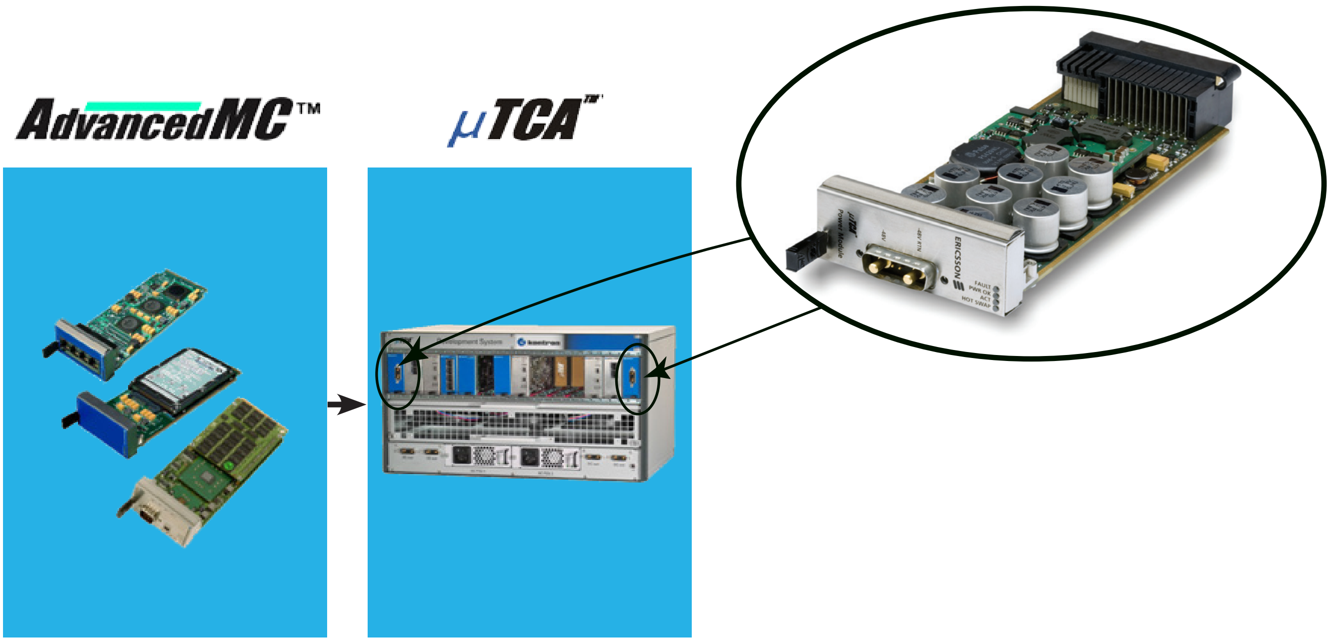



Figure 1 – MicroTCA sub-rack holding AdvancedMCs and power modules

## 3. MICROTCA POWER MODULE

The power module provides both payload (12 V) and management (3.3 V) power for all of the loads in the MicroTCA enclosure. These loads may include 2 Cooling Units (CU) and 2 shelf-level MicroTCA Carrier Hubs (MCH) in addition to the maximum of 12 AdvancedMC modules, resulting in a maximum of 16 "channels" of output power. Over and above the power channels, the MicroTCA specification requires other functional content in the power module, resulting in the following list of functional requirements:

- INPUT POWER O-RING
- HOTSWAP CONTROL FOR INPUT POWER INRUSH PROTECTION
- INPUT POWER FILTERING
- POWER HOLD-UP CAPACITANCE
- 48 V TO 12 V DC/DC CONVERSION (PAYLOAD POWER)
- INPUT TO OUTPUT ISOLATION
- 12 V TO 3.3 V CONVERSION (MANAGEMENT POWER)
- OUTPUT POWER DISTRIBUTION
- HOTSWAP CONTROL FOR MULTIPLE ADVANCED MCS,CUS, MCHS
- OUTPUT POWER MONITO-RING AND CONTROL
- OUTPUT POWER PROTECTION CIRCUITRY

The consolidation of both power handling circuitry and system level control/management functionality into the relatively small centralized MicroTCA power module means that the power module design, performance and reliability are all crucial to the success of the overall system. The power module and particularly the 12 V Intermediate Bus Converter (IBC) function internal to it will be described in more detail in the remainder of this paper. *Figure 2* contains a block diagram showing the content of a typical MicroTCA power module.

In MicroTCA "raw" DC input power is supplied directly to the input connectors on the front of the power module. Therefore the power module must contain the necessary power conditioning and filtering that is done externally with some other architectures. Fusing in MicroTCA systems is typically done in a power distribution unit by providing fuses for each of the cables that distribute input power to the front of the power modules. Consequently, no internal fuses are normally contained within a power module. Other front-end functions are EMI filtering, inrush current limiting, hold-up capacitance and input power feed O-Ring diodes if used. A MicroTCA power module may be configured with either a single feed or with two redundant feeds.

The power module contains a -48 V to 12 V isolated DC/DC converter function with power levels up to 600 W. A Point of Load (POL) regulator from the 12 V output is used for generation of 3.3 V management power. Additional POLs, within the AdvancedMC modules are used to derive their needed low voltage power from the 12 V payload power. The control mechanism for MicroTCA power modules is the Enhanced Module Management Controller (EMMC), which monitors and controls both management and payload power for all of the AdvancedMCs, CUs and MCHs configured in the system. Communication between the EMMC and the external MCHs is done by means of the Intelligent Platform Management Bus (IPMB).

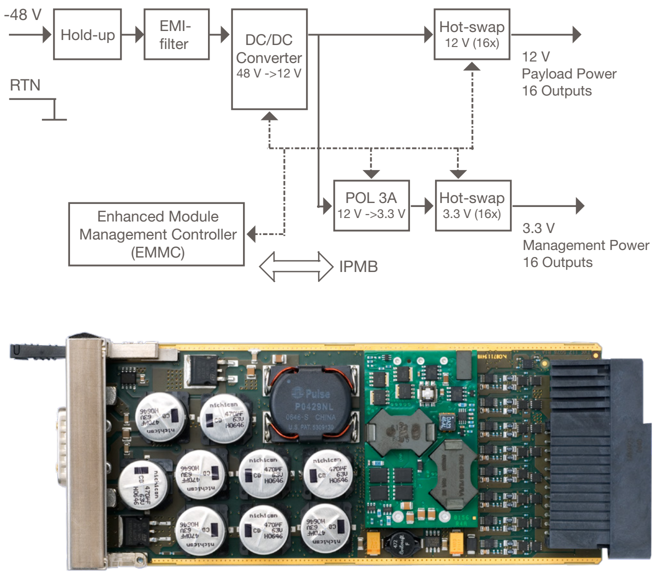



Figure 2 – Block diagram and overview of

*Figure 2* also contains a photograph of an actual power module, an Flex ROA 117 5078/1. This is an existing production module capable of up to 355 W of output power and is packaged in a "Single-Width Full-Height" form factor with approximate external dimensions of 74 by 187 by 29 mm. Some MicroTCA systems require power modules with up to 600 W of output power in the same package size. This requirement results in very high power conversion density and substantial design challenges for the power module if the desired reliability levels are to be maintained. Consequently, high efficiency is at the top of the list of design requirements. The remainder of this paper will delineate some of the design challenges posed by delivering more power in this same form factor and discuss proposed solutions to them. It will be demonstrated that digital control techniques offer opportunities for optimization of such a 600 W power module. For more complete information on the specification and implementation of MicroTCA power modules, the reader is directed to references [5] and [7].

## 4. POWER MODULE DESIGN CHALLENGES

The introduction summarizes the content of a MicroTCA power module and indicates that the design of a 600 W product is not a trivial exercise. We will next examine the design challenges of such a product in more detail, with emphasis on four different areas. Later, we will examine how digital control techniques can be used to turn these challenges into opportunities for enhanced performance and exciting products. While this information is presented within the context of a MicroTCA power module, the design challenges and proposed solutions will in many cases also apply to other more generic products such as IBCs intended for distributed power systems.

### 4.1 POWER DENSITY AND EFFICIENCY

Our goal of increasing the power module output power from 355 W to 600 W within the same physical form factor results in a significant increase in power density. The higher power demand has ramifications beyond the ratings of the 12 V DC/DC converter and 3.3 V POL regulator, as the capacity of the input filtering and hold-up capacitance must be correspondingly increased. The limitation, of course, is thermal dissipation within the confines of the power module, which should not exceed a total of 40 W for the single-width form factor. Our goal is to achieve an ambitious efficiency of 96% for the DC/DC converter function which will result in a maximum of 25 W of dissipation for this function, leaving 15 W of the 40 W budget available for dissipation in areas such as input filtering, power management components and output distribution losses.

### 4.2 CONDUCTED EMI

The power module must meet the class B conducted Electromagnetic Interference (EMI) requirements of EN55022 (CISPR22) and Telcordia GR-1089. A class B EMI filter at the 600 W power level can occupy a significant amount of circuit board area when used with conventional DC/DC converters, resulting in contention for space within the power module. To help solve this problem, our engineering objective is to design the DC/DC converter so that it is "filter friendly", imposing a minimal demand on the conducted emission filter with a goal of minimizing its size and cost.

### 4.3 OUTPUT VOLTAGE TOLERANCE

The required output voltage tolerance on the power module 12 V payload output depends on whether power module redundancy is used in the MicroTCA system design. The MicroTCA specification does include provision for redundant power modules to increase system availability in critical applications. When needed, this capability can function quite well and achieve the system availability goals. It is important to understand, however, that power modules designed for redundant operation are inherently more complex and costly than power modules intended for stand-alone operation. A brief description of the MicroTCA power module redundancy scheme and its impact on output voltage tolerance requirements is presented here. Readers desiring more detail on the redundancy implementation and other power related impacts of the redundancy trade-off are directed to reference [5].

The MicroTCA specification requires that any given power module be identified to the system as either a primary power module or a redundant power module. In the event of a failure in any output channel of a primary power module, the redundant power module will take over responsibility for all output channels of that primary power module, not just the failed channel. Automatic transition between a failed primary power module and the redundant power module is accomplished by the settings of their output voltages. Primary power modules are set to a higher output voltage than redundant power modules, the two nominal settings being perhaps 12.5 V and 11.5 V. This output O-Ring allows instantaneous and automatic transition in the event of a failure due to the power module with the higher output voltage delivering power to the loads. This technique also imposes much more stringent voltage budgets and output regulation requirements on power modules used in redundant systems.

We will now examine the impacts of redundancy on the 12 V DC/DC converter. The basic MicroTCA specification defines the tolerance range for the AdvancedMC module input voltage as 10 V to 14 V. Since the load module will operate at any voltage in this range, the 12 V DC/DC converter could have a +/- 10% tolerance in a non-redundant system. In a redundant system, the situation becomes more challenging. In order to keep the voltage budgets of both the primary and the redundant power modules within the same overall range at the AdvancedMC inputs without possibility of overlap, the tolerance ranges for the primary power module would be approximately 12.25 V to 12.95 V and the range for the redundant power module from 11.6 V to 12.0 V. These ranges include the effects of line and load regulation as well as temperature. This means that the DC/DC converter in a power module intended for operation in a redundant system must have a +/- 2% output voltage tolerance. Going from a +/- 10% to a regulation tolerance of about +/- 2% has a significant impact on the DC/DC converter design.

A meaningful analysis and quantification of the above impact can be obtained by looking at two production DC/DC converters in the Flex product line.

*Figure 3* summarizes the parameters of two Flex DC/DC converters with 12 V outputs and approximately the same input voltage range. They are both very contemporary designs and are highly regarded as representing industry-leading performance in terms of efficiency and power density given their respective design assumptions. They both have exactly the same form factors and total PCB area. The PKM 4304B is more loosely regulated with only feed-forward regulation from the input line voltage and no load regulation feedback loop. This greatly simplifies the module's control system, but does create a droop in its output load characteristic as shown in *Figure 4*. The additional space freed up by the less complex control system was used to enhance the power train resulting in high efficiency (95.3%) and output power (380 W). This converter could be used in a power module not intended for redundant applications.

The PKM 4313C, in the same size physical package, contains output voltage feedback and features output voltage regulation of +/- 2.5%, close to the performance suitable for usage in a power module for redundant applications. But there are penalties for this enhanced performance.

The efficiency is 93.3%, significantly lower than that of the PKM 4304B. Also, the maximum power output is 204 W. The power density is only 54% that of the PKM 4304B. We can conclude from this that power modules used in redundant systems will have higher power losses than those intended for non-redundant systems, and that their internal packaging will be more challenging.

| PKM 4313C PI | |
|---|---|
| INPUT RANGE | 38 - 75 VDC |
| SIZE | 36.8 X 57.9 MM (WXL) |
| VOUT TOLERANCE | +/- 2.5% |
| EFFICIENCY | 93.3% (48 V IN, MAX LOAD) |
| OUTPUT POWER | 204 W |

| PKM 4304B PI | |
|---|---|
| INPUT RANGE | 36 - 75 VDC |
| SIZE | 36.8 X 57.9 MM (WXL) |
| VOUT TOLERANCE | - 10.8 / +4.2% |
| EFFICIENCY | 95.3% (48 V IN, MAX LOAD) |
| OUTPUT POWER | 380 W |

Figure 3 – DC/DC converters with 12 V outputs

Consequently, our design goal of achieving 96% conversion efficiency at 600 W output in a restrictive power module form factor in conjunction with +/- 2% regulation for redundant applications is indeed a challenging one!

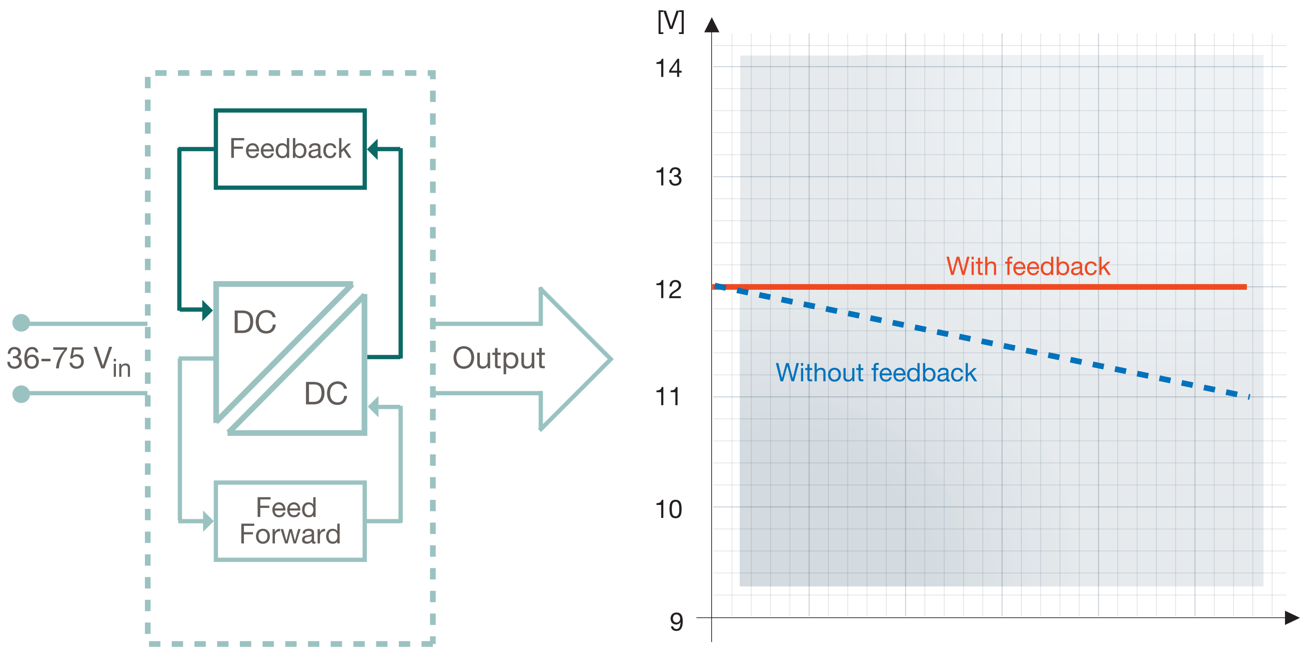



Figure 4 – Performance comparison with and without feedback loop

### 4.4 ENERGY MANAGEMENT

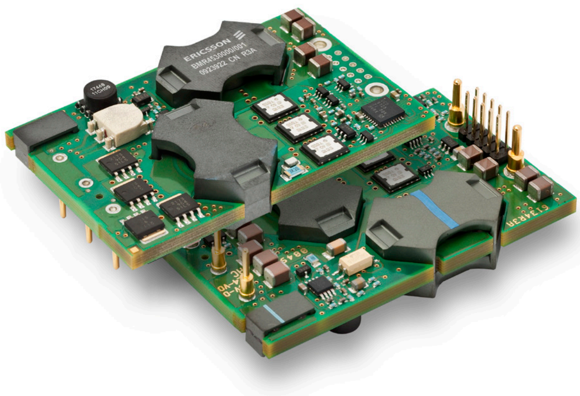
The power module contains an EMMC which communicates with the shelf-level MCH via two redundant 2 wire serial IPMBs as shown in *Figure 2*. The EMMC also communicates with the DC/DC converter. Since the DC/DC converter function is being done with a new design, it is possible that an innovative approach to the converter and its interconnection with the EMMC could achieve new capabilities in terms of intelligent energy management for the converter and result in benefits to the entire MicroTCA system. The new converter design then creates an opportunity for enhanced system level performance.

## 5. DIGITAL SOLUTIONS TO DESIGN CHALLENGES

Now that the challenges and objectives have been identified, we will describe an approach that provides solutions to all of them. After an overview of the proposed general implementation of the converter and control functions of the MicroTCA power module, more detailed data will be supplied showing how each of the four areas of concern have been addressed. In addition, it will be shown that the proposed solution may offer additional benefits to the power module and the MicroTCA system over and above the stated objectives.

### 5.1 OVERALL APPROACH

The solution proposed for the high performance MicroTCA power module is configured around a new Flex isolated DC/DC converter operating from the -48 V telecom input source and providing 12 V output at up to 396 W. The converter features a +/- 2% output voltage tolerance and is packaged in a ¼ brick package. It utilizes a full-bridge topology operating at a switching frequency of 150 kHz. A summary of the converter features and photographs of its construction are shown in *Figure 5*.



| KEY FEATURES OF NEW DC/DC CONVERTER | |
|---|---|
| FORM FACTOR | ¼-BRICK (2.28 X 1.45 IN.) |
| INPUT VOLTAGE | 36 - 75 V |
| OUTPUT VOLTAGE | 12 V ± 2% |
| OUTPUT POWER | 396 W |
| SWITCHING FREQUENCY | 150 KHZ |
| CONTROL IC | DIGITAL MICRO CONTROLLER |
| REGULATION | $V_{OUT}$ FEEDBACK |
| TOPOLOGY | FULL-BRIDGE |

Figure 5 – DC/DC converter with digital control

For comparison purposes, the PKM 4304B and the PKM 4313C mentioned previously use the same package size, but with significantly different power levels and output voltage tolerances. The PKM 4304B is capable of 380 W of output power but is loosely regulated with no output voltage feedback. Consequently it would not be suitable for use in a power module for a redundant MicroTCA system. The PKM 4313C is capable of tight output regulation, but can only deliver a maximum of 204 W under these conditions. Therefore, the new converter to be discussed here represents a substantial performance breakthrough even when compared to the referenced converters, which were considered state-of-the-art just a year ago.

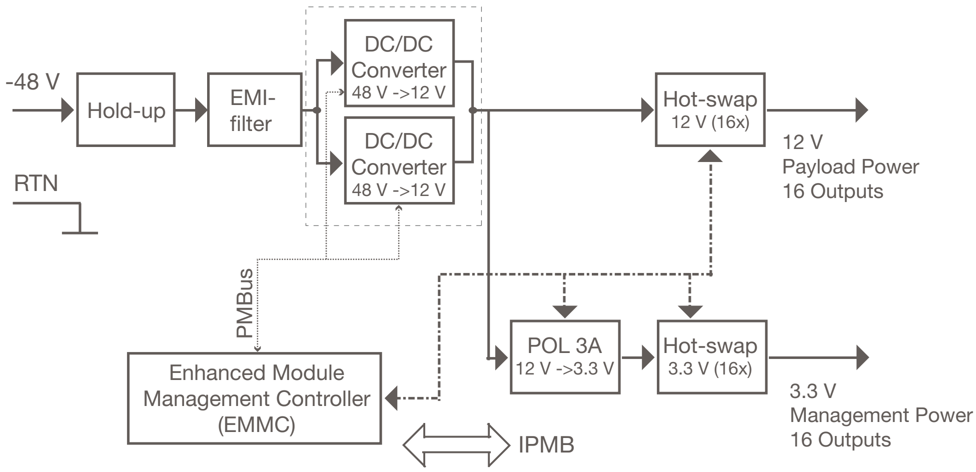
The enabling technology that allows for this significant advancement is digital control within the DC/DC converter. The conventional analog control IC was replaced with a digital micro controller. This technique has just recently become viable due to the better availability of lower cost high performance micro controllers suitable for use in power supplies. Most of the power train components of the converter remain the same as with an analog implementation. The micro controller, however, sweeps up a large quantity of discrete control and overhead components resulting in better integration, lower component count, less PCB area, and improved reliability. All this is reflected in the higher power density achieved by this converter. Additional detail about this converter design can be found in reference [6].

## 5.2 POWER DENSITY AND EFFICIENCY

The goal of 96% efficiency is a difficult one, but the paralleled converters are able to achieve it. The two converters normally behave as one higher power converter by means of an active current sharing connection between them. This connection is established via the communication interface connector that connects the dedicated current share pins on the converters, and the converters themselves regulate the current sharing without intervention from the EMMC. The PMBus connection from the converters to the EMMC is however used for other purposes as will be described later. Neither the converter to converter current sharing operation nor the EMMC to converter PMBus traffic interferes with the MCH to EMMC communication on the IPMB. No external components are required for the current sharing implementation, and current sharing to within 7-10% is targeted. The projected maximum current capability of two of these paralleled converters in other applications is up to 736 W.

The measured efficiency of the paralleled converter implementation is shown in *Figure 7*. The 96% efficiency objective is met at output loads from 40% to 100% of full load (20 to 50 A), which is outstanding performance. Note that the paralleled converters with current sharing can actually supply over 60 A of current, well above the rating for this power module application. This can be considered either as extra margin for increased reliability or as an opportunity for higher output power in future applications.

For this MicroTCA power module application two of these converters are operated in parallel to form a single high output power converter function that is capable of supplying the desired 600 W output power level. A PMBus is used for communication between the two converters and to the EMMC. A block diagram of the resulting power module architecture is shown in *Figure 6*. The dashed lines surrounding the two converter blocks indicate that they should be functionally considered as a single 600 W converter. The details of how this is accomplished and the resulting benefits are discussed below.




| ENERGY MANAGEMENT FEATURES | |
|---|---|
| PMBUS INTERFACE | EMMC <-> DC/DC |
| SYNCHRONIZATION | DC/DC <-> DC/DC |
| CURRENT SHARE | DC/DC <-> DC/DC |

Figure 6 – DC/DC converters with PMBus interfaces operating in parallel

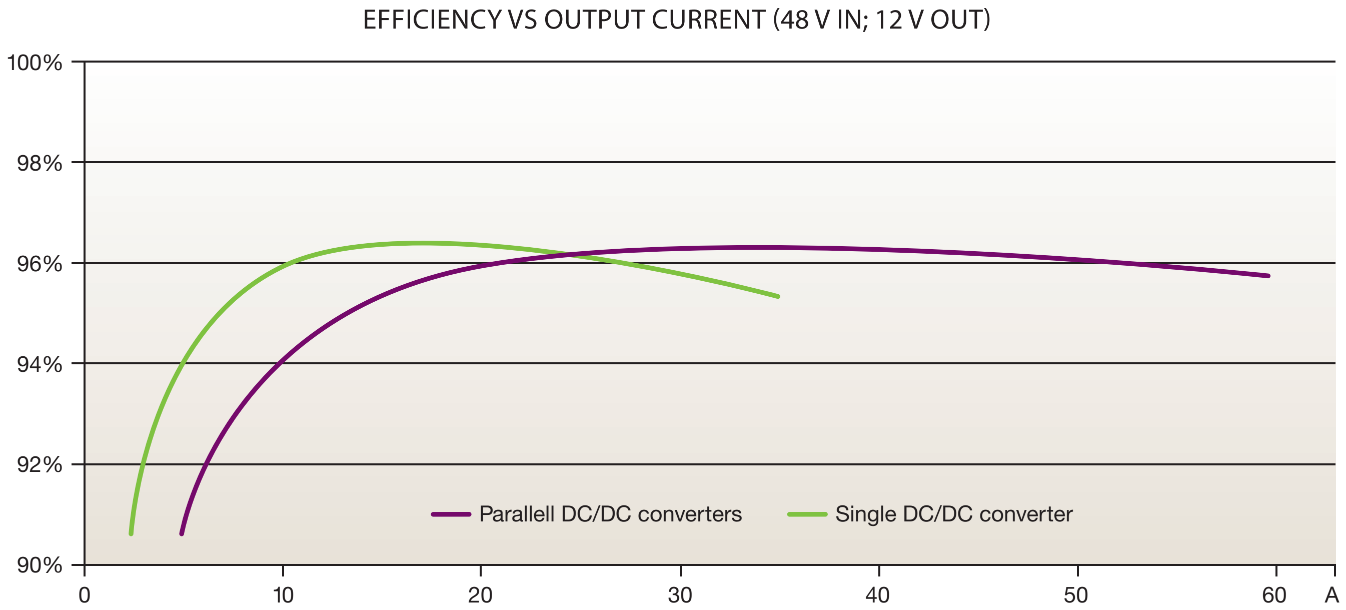



Figure 7 – Efficiency of the paralleled DC/DC converter implementation

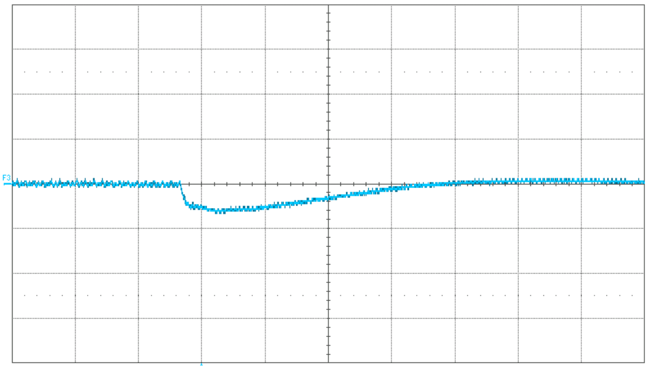
Note that there is a second efficiency curve displayed in *Figure 7*. This is the measured efficiency of a single converter with output currents up to 33 A. As would be expected, the efficiency peak is at a lower current value than that of the paralleled converters. We believe that this characteristic creates an opportunity for further enhancing the performance of the power module. Consider a scenario where the EMMC determines the system current demand via communication with the MCH and automatically switches the DC/DC converter function from a current shared paralleled connection to a single converter when the system current requirements are low. This communication would be done via the PMBus. The negotiated switching point would need to contain a fair amount of "overlap" so that a single converter would not be operated near its maximum current rating to avoid overcurrent conditions.

With the automated converter changeover capability described above, the composite efficiency curve is truly impressive. The 96% efficiency objective is met with output loads from 20% to 100%. The efficiency is above 90% even at loads down to 2.5 A. This approach results in a significant savings in power losses. At light system loads, the switching losses of a single converter will be about half those of two paralleled converters. This is a very exciting result and should create exceptional benefit for MicroTCA system designers as well as other DC/DC converter users. It is a good example of how digital power control can create unexpected new capabilities and functionality.

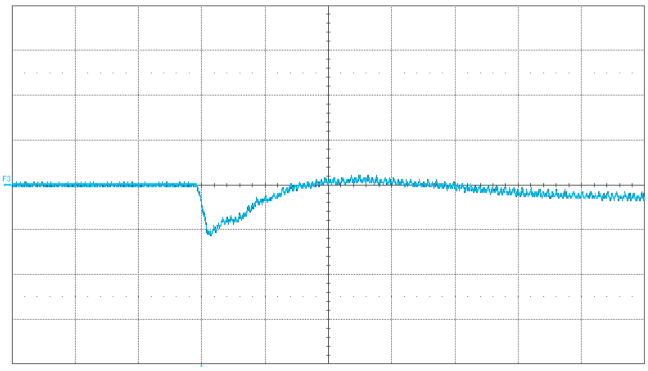
Practical implementation of this automated converter selection capability will require seamless switchover without disruption to the system 12 V load or generation of any fault conditions. Some preliminary testing was done to assess the performance of the switchover from individual to paralleled operation. The upper oscilloscope trace in *Figure 8* shows the effect on the output voltage of switching from a paralleled converter connection to an individual converter. The test was done at an output load current of 20 A, so the operational converter sees an output current transition from 10 A to 20 A. This current change results in a slight depression in the output voltage – about 300 mV for a duration of 170 µs. This should not create any difficulties for the system.

## OUTPUT VOLTAGE

Disable DC/DC converter (2->1)



Enable DC/DC converter (1->2)



| Test conditions | |
|---|---|
| 48 V in & 12 V out | 2.2 mF output capacitance |
| 20 A output | No O-Ring on output |
| 500 mV/div | Current share: DC/DC <-> DC/DC |
| 50 µs/div | Enable: EMMC <-> DC/DC |

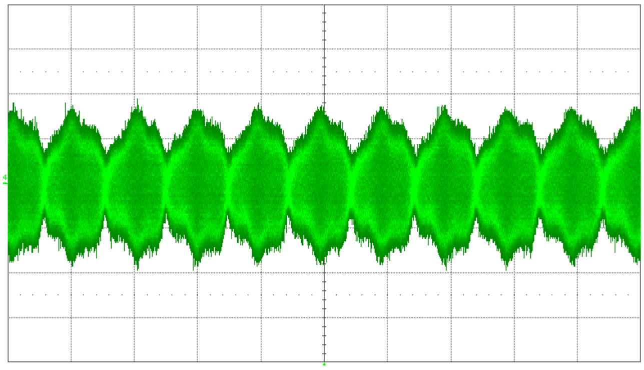
Figure 8 – Transition between single and parallel DC/DC converter operation

A more demanding condition occurs when switching from one converter to a paralleled connection. Synchronous rectification is used in the converters to maximize efficiency, so the output rectification is implemented with MOSFETs, which can conduct current in either direction. This can create difficulties when starting up into a pre-biased load, which is exactly the scenario presented with the start-up of the second converter in the paralleled configuration. Without proper management of the start-up, the converter could be overstressed or damaged by a reversed current and there could be a significant dip in the output voltage. O-Ring diodes could be used as a solution, but were rejected due to their negative impact on efficiency and component space. Instead, the O-Ring function is implemented with intelligent control of the output transistors. This approach would normally require the addition of a specialized controller IC, but with the digital control implementation of these converters the start-up control is handled by the existing on-board micro controller without the need for any additional components. The feasibility of this approach is demonstrated in the lower oscilloscope trace in *Figure 8*. The dip in the output voltage is due to some current being conducted into the second converter on start-up, but this current is at a safe level for the converter. The 500 mV dip in output voltage is more than desirable, however, and further work is under way to improve this aspect of the performance. We do believe, however, that these initial results are very encouraging and represent a meaningful advancement in the ability to achieve high efficiency over a very wide range of output current.

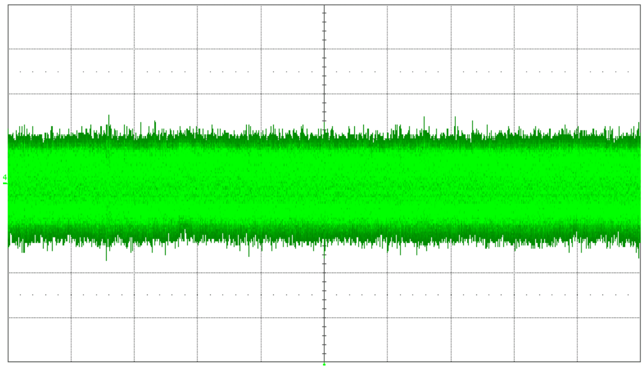
Another possible extension of this implementation would be to automatically reconfigure the power module to operate at a lower power level (up to 396 W) in the event of a failure in one of the paralleled DC/DC converters. This could achieve a temporary reduced performance mode until the power module could be replaced. This operation is currently not supported by the MicroTCA specification and would need to be collaborated with the design of the MCH. However it could be a possible way to create some additional redundancy and reliability within MicroTCA for those systems with a scalable output power.

## AC INPUT RIPPLE CURRENT

Synchronization disabled



Synchronization enabled



| Test conditions | |
|---|---|
| 48 V in & 12 V out | 150 kHz |
| 0 A output | 90° Interleaving |
| 200 mV/div | No filter on input |
| 5 ms/div | |

Figure 9 – Synchronization and interleaving

### 5.3 CONDUCTED EMI

One of the objectives of this project was to design the DC/DC converter function of the power module so that the size and complexity of the class B conducted EMI filter is minimized. This objective was accomplished by designing the paralleled DC/DC converters to automatically synchronize their switching frequencies. The synchronization is accomplished with a direct connection between the two converters so that no intervention is needed from the EMMC via the PMBus. The synchronization is done in a "master-slave" implementation. The slave converter assumes the same operating frequency as the "master", but with a 90 degree phase shift between them. This phase shift is critical for the purpose of minimizing the input ripple current of the combined converters with the interleaved full-bride topology.

The effect of this approach on the input ripple current is dramatic as shown in *Figure 9*. The maximum ripple current (and most stringent EMI criteria) for this topology actually occurs at light load, so the testing was done with no load on the output. The upper trace displays the input current with the synchronization feature disabled, and the lower trace the input current with the synchronization feature enabled. The significant reduction in ripple current in the lower trace demonstrates the effectiveness of this solution, and allows for a very small and compact implementation of the conducted EMI filter function.

### 5.4 OUTPUT VOLTAGE TOLERANCE

The objective of a +/- 2% output voltage tolerance while maintaining excellent efficiency as identified in section 4.3 has been met in this design, and documented in the discussion and test data presented in section 5.2

### 5.5 ENERGY MANAGEMENT

We have already described the two bus structures used in conjunction with the power module, the internal PMBus from the EMMC to the DC/DC converters and the external IPMB from the EMMC to the system MCH. We will now look at their implementation in more detail and also consider how they may be utilized in order to maximize the functionality of the power module and the total MicroTCA system. The EMMC could be implemented with a FPGA chip. Not all of the chip's gates and I/O pins are required to configure the EMMC functions. The unused portion of the chip may instead be used to create the PMBus host controller, which primarily communicates with the two DC/DC converters via the two wire serial PMBus. This sharing of the FPGA between two functions results in a net reduction of needed components.

The EMMC would normally be connected to sensors located within the confines of the power module to measure data such as the system input voltage and internal power module temperatures. This information would then be sent to the MCH via the IPMB. With the implementation shown in *Figure 6*, some of these sensors and associated interconnections are not needed. Instead, the required data can be obtained directly from the DC/DC converters via the PMBus, resulting in additional hardware savings. There is also an opportunity to leverage the PMBus further by connecting it to functions such as the hotswap controllers.

In addition to reducing the number of discrete components in the system, the usage of the PMBus creates an opportunity for increased functionality and flexibility during all phases of the product life cycle. Some of these are summarized below.

CONVERTER DESIGN

- CHANGE OPERATING PARAMETERS SUCH AS OVERCURRENT LIMIT, FEEDBACK COMPENSATION, START-UP PROFILES, AND CONTROL OF OUTPUT RECTIFIERS
- CHANGES VIA SOFTWARE RATHER THAN SOLDERING IRONS AND PCB LAYOUT CHANGES
- FASTER DESIGN AND TIME-TO-MARKET

CONVERTER AND POWER MODULE MANUFACTURING

- SET OUTPUT VOLTAGE, CURRENT LIMITS, ETC.
- ADJUST FOR PROCESS VARIATIONS
- CONDUCT MARGIN TESTING

SYSTEM INTEGRATION AND FIELD DEPLOYMENT

- MONITOR AND ADJUST SYSTEM VOLTAGES
- DETECT AND RESPOND TO FAULT CONDITIONS

The above is only an abbreviated indication of the rich possibilities afforded by the usage of digital control for energy management purposes. References [4], [5], and [6] contain additional detail about these areas and are a source of many more ideas for utilizing the capabilities of the communication busses during the product life cycle.

## 6. CONCLUSIONS AND SUMMARY

This paper has set some aggressive objectives for various aspects of a new 600 W output MicroTCA power module. We have demonstrated that the design meets all these objectives as well as offering opportunities for additional features. The solutions to the stated objectives can be summarized as follows:

- THE 96% EFFICIENCY TARGET WAS MET OVER AN EXTREMELY WIDE RANGE OF OUTPUT CURRENT – 20 TO 50 A FOR THE CURRENT-SHARED PARALLELED CONVERTER IMPLEMENTATION, AND 10 TO 50 A WHEN AUTOMATED CONVERTER RECONFIGURATION IS USED
- TOTAL CONVERTER POWER DISSIPATION IS LESS THAN 25 W, WHICH GIVES APPROXIMATELY 12.5 W PER ¼- BRICK.
- A "FILTER FRIENDLY" CONVERTER DESIGN FEATURING SYNCHRONIZATION AND PHASED INTERLEAVING WAS ACCOMPLISHED, RESULTING IN MINIMAL INPUT RIPPLE CURRENT AND SIZE/COMPLEXITY/COST SAVINGS FOR THE CLASS B CONDUCTED EMISSIONS EMI FILTER
- +/- 2% OUTPUT VOLTAGE REGULATION WAS DEMONSTRATED, MAKING THE POWER MODULE SUITABLE FOR REDUNDANT APPLICATIONS
- EXCEPTIONAL POWER DENSITY WAS ACHIEVED, EVEN WITH THE TIGHT REGULATION VIA OUTPUT VOLTAGE FEEDBACK
- ENERGY MANAGEMENT TECHNIQUES WERE DEMONSTRATED, MAKING USE OF THE EMMC AND PMBUS SERIAL INTERFACE

Accomplishments over and above the stated objectives include:

- IMPLEMENTATION OF SYNCHRONIZATION, CURRENT SHARING AND THE PMBUS WITHOUT THE NEED FOR ADDITIONAL COMPONENTS
- SHARING A SINGLE FPGA FOR BOTH EMMC AND PMBUS HOST FUNCTIONALITY
- A TECHNIQUE WAS PRESENTED FOR AUTOMATED RECONFIGURATION OF THE DC/DC CONVERTERS TO OPTIMIZE EFFICIENCY OVER AN EXTREMELY WIDE CURRENT AND POWER RANGE
- A PROPOSED EXTENSION OF THE MICROTCA SPECIFICATION WAS PRESENTED THAT COULD INEXPENSIVELY ADD REDUNDANCY AND RELIABILITY TO POWER MODULES BY AUTOMATICALLY OPERATING AT REDUCED POWER WITH A SINGLE CONVERTER IN THE EVENT OF A CONVERTER FAILURE

The ability to automatically switch from one to two operating DC/DC converters was demonstrated, but the resulting output voltage dip was higher than desired due to the current into the second converter during start-up. Additional effort and design improvements are needed to optimize this operation.

While each of the above individual objectives and features could have been accomplished in any of several ways, including analog approaches, we feel that the digital control approach presented here was instrumental in meeting all of them within the confines of this high density package. High efficiency, high power density, tight output regulation, easy EMI filtering and an extensive list of digitally controlled features was accomplished along with a significant reduction in parts count. In summary, the work presented here has been very successful, and we are excited about its use in 600 W MicroTCA power modules as well as in traditional distributed power architectures.

## 7. GLOSSARY

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| AdvancedMC™, AMC | Advanced Mezzanine Card |
| AdvancedTCA™, ATCA | Advanced Telecommunications Computing Architecture |
| CPE | Customer Premises Equipment |
| CU | Cooling Unit |
| EMI | Electromagnetic Interference |
| EMMC | Enhanced Module Management Controller |
| ETSI | European Telecommunications Standards Institute |
| FPGA | Field Programmable Gate Array |
| IBC | Intermediate Bus Converter |
| IC | Integrated Circuit |
| ICT | Information and Communications Technology |
| I/O | Input/Output |
| IPMB | Intelligent Platform Management Bus |
| MCH | MicroTCA Carrier Hub |
| MicroTCA™ | Micro Telecommunications Computing Architecture |
| MOSFET | Metal Oxide Semiconductor Field Effect Transistor |
| PCB | Printed Circuit Board |
| PICMG™ | PCI Industrial Computer Manufacturers Group |
| PMBus™ | Power Management Bus |
| POL | Point of Load |

## 8. REFERENCES


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7. MicroTCA Power Module Preliminary Datasheet, Flex Power Modules, September 2007


All referenced papers and data sheets can be found at Flex Power Modules' web site: http://www.Flex.com/powermodules

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