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Using the MCP16311/2 Synchronous Buck Converter Design Analyzer

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INTRODUCTION

As increasingly more electronic equipment is developed in different fields of interest, and demands for longer run time and higher efficiency escalate, electrical system design engineers are now facing the difficulties of developing better and more efficient power supplies that can meet the requirements and standards in the industry.

Unfortunately, in many cases, the power supply design process is among the most troublesome parts of the project and requires a lot of time and effort.

In order to help engineers cope with the complexity of developing the power supplies best suitable for their design, IC manufacturers are providing power supply design tools, such as the Microchip Technology Incorporated MCP16311/2 Design Analyzer. This tool represents a superior alternative to the trial-and-error approach, which is both time and resource consuming as it involves repeatedly developing and testing prototypes until satisfactory results are obtained.

A design tool can help choose the best components and can provide an insight into how the power supply is going to behave under different conditions. By doing so, it provides valuable information long before receiving the actual board from the factory.

The Microchip MCP16311/2 Design Analyzer is a Microsoft® Excel®-based tool that calculates and recommends the most suitable components for user-specific applications. Furthermore, it has the option of tuning your external components in order to get the best results. By using the components and conditions specified in the input cells, the MCP16311/2 Design Analyzer can estimate the efficiency and frequency response of the power supply.

SYNCHRONOUS BUCK CONVERTER

Figure 1 shows an idealized version of a buck converter. In a traditional converter, the S_2 switch would have been a diode. This is still practiced in many of today's buck converters, as it offers increased simplicity in terms of control while being cost effective at the same time.

Although such an asynchronous solution may seem simpler and cheaper, it can also prove ineffective, especially when targeting low output voltages.

For this reason, a synchronous solution was developed which involves replacing the S_2 switch with a MOSFET, thus increasing efficiency and output current capabilities.

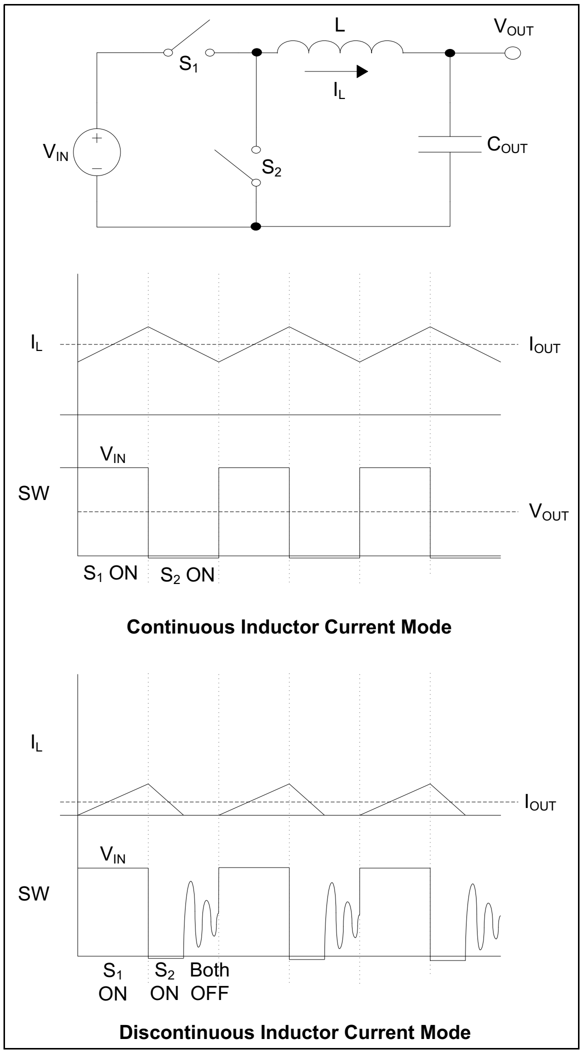


FIGURE 1: *Buck Converter - Topology and Waveforms.*

The basic operation of the buck converter can be illustrated by looking at the two current paths represented by the state of the two switches:

- S_1 - the high-side switch
- S_2 - the low-side switch

When the high-side switch is turned on, a DC voltage is applied to the inductor equal to V_{IN} - V_{OUT}, resulting in a positive linear ramp of inductor current.

Conversely, when the high-side switch turns off and the low-side switch turns on, the applied inductor voltage is equal to $-V_{OUT}$, which results in a negative linear ramp of inductor current.

In order to make sure there is no shoot-through current, a dead time where both switches are off is implemented between the high-side switch turning off and the low-side switch turning on and vice-versa.

A buck converter operates in Continuous Inductor Current mode if the current through the inductor never falls to zero during the commutation cycle. Provided that the inductor current reaches zero, the buck converter operates in Discontinuous Inductor Current mode.

The two modes of operation are represented in Figure 1.

Typically, by using a synchronous solution, the converter is forced to run in Continuous Inductor Current mode no matter the load at the output. This, in turn, causes losses at low loads as the output is being discharged.

One solution to this problem, which is also applied in the design of the MCP16311/2, is to use a zero-current comparator. This comparator monitors the current through the low-side switch, and when it reaches zero, the switch is turned off.

This feature is called *diode emulation* and, by implementing it, the converter will have the advantages of both Synchronous and Asynchronous modes of operation.

MCP16311/2 SHORT OVERVIEW

The MCP16311/2 device is a compact, high-efficiency, fixed frequency, synchronous step-down DC-DC converter in an 8-pin MSOP or 2x3 TDFN package that operates using input voltage sources of up to 30V.

Integrated features include a high-side as well as a low-side switch, fixed frequency peak current mode control, internal compensation, overcurrent limit and undervoltage lockout overtemperature protection.

High converter efficiency is achieved by integrating the low-resistance, high-speed low-side and high-side switches as well as associated drive circuitry.

In order to deliver high efficiency over the entire load range, starting from ~100 µA up to 1A, the MCP16311 can run in both Pulse-Width Modulation (PWM) and Pulse-Frequency Modulation (PFM) mode. It switches to PFM mode for light load conditions and for large buck conversion ratios. The MCP16312 can run in PWM-only mode.

MCP16311/2 Features

- Input Voltage Range: 4.4V to 30V with UVLO at 4.1V to start and 3.6V to stop
- Up to 1A Output Current Capability
- Integrated low-side (R_{DSON}: 170 mΩ) and Integrated high-side (R_{DSON}: 300 mΩ)
- Switching Frequency: 500 kHz
- Reference Voltage: 0.8V
- Adjustable Output Voltage from 2V to 24V
- Automatic Pulse-Frequency Modulation/Pulse-Width Modulation (PFM/PWM) for the MCP16311 or PWM-only operation for the MCP16312
- Low Device Quiescent Current: 44 µA (non switching) for MCP16311
- Low Device Shutdown Current: 4 µA
- Soft-start: 300 µs
- Peak Current Mode Control
- Thermal Shutdown: 150°C with 25°C hysteresis

PFM/PWM Operation

In order to further increase the efficiency at light loads, in addition to diode emulation, the MCP16311 features a Pulse-Frequency Modulation (PFM) mode of operation.

When in this mode, compared to the traditional Pulse-Width Modulation (PWM), the MCP16311 increases the output voltage just up to the point after which it enters a “sleep” mode. During this dormant state, the device stops switching and consumes only 44 µA of the input. When the output voltage drops below its nominal value, the device restarts switching and brings the output back into regulation.

An instance of PFM operation is represented in Figure 2 and can be easily identified by the triangular waveform at the output of the converter.

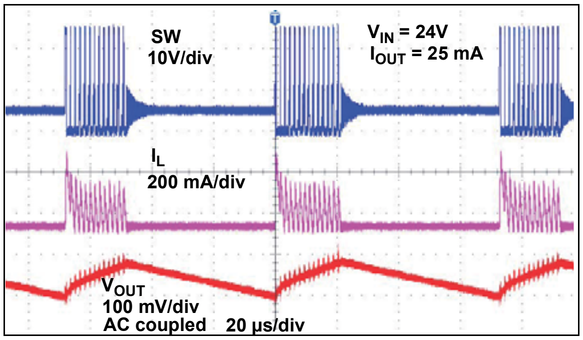


FIGURE 2: *MCP16311 - PFM Operation.*

The PFM mode of operation considerably increases the efficiency of the converter at light loads, while also adding a lower-frequency component at the output which varies with the input voltage, output voltage and output current.

Once the output load increases, the converter transitions to normal PWM operation. The threshold point is determined by the input-to-output voltage ratio and by the output current.

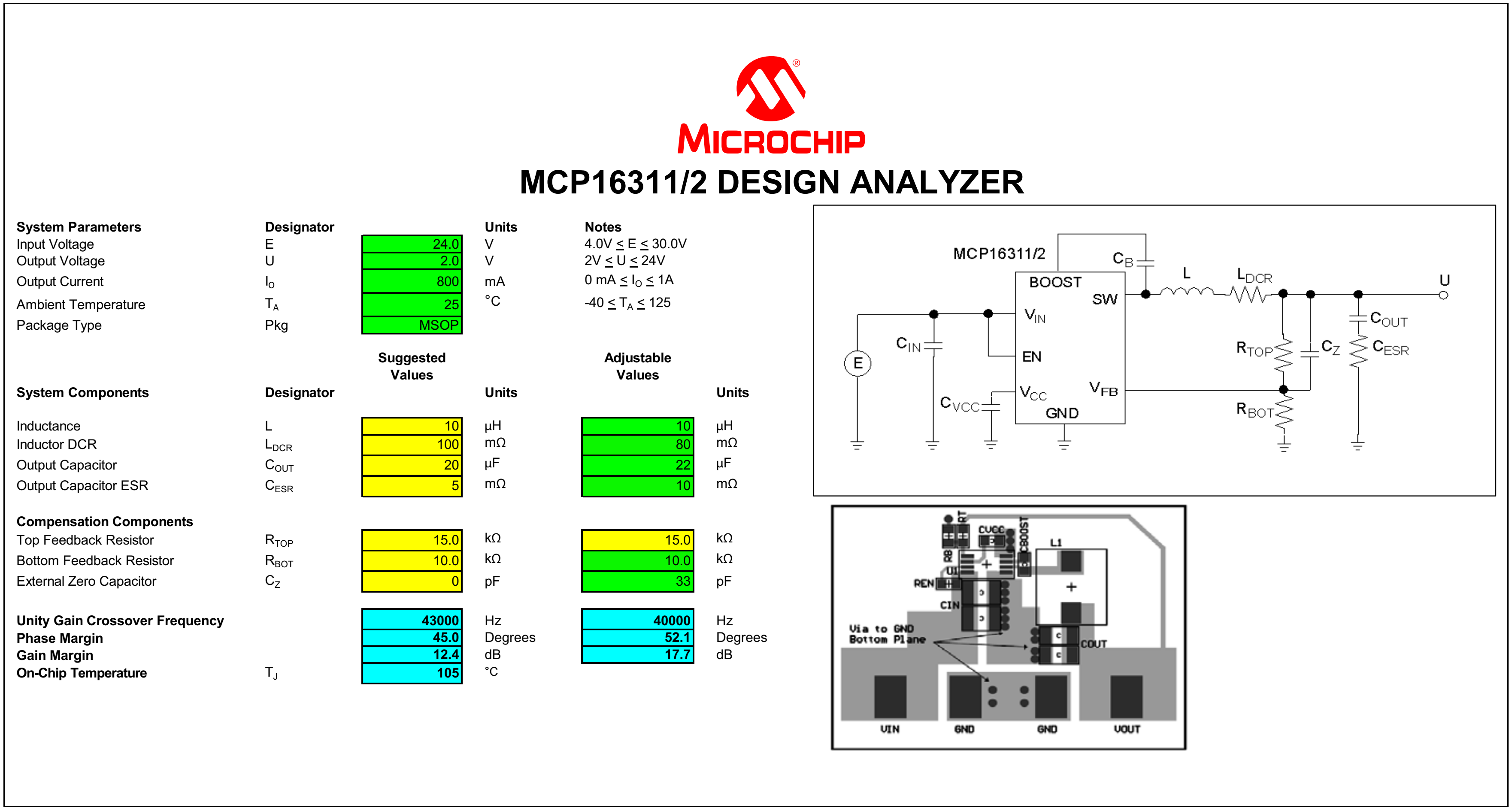
Because of the triangular waveform at the output, in more sensitive applications, the use of the MCP16312 is recommended because it runs in PWM mode.

MCP16311/2 DESIGN ANALYZER

The MCP16311/2 Design Analyzer is a simple Excel tool that provides the user with a classic interface, laid out as predefined cells, in which various system parameters have to be defined.

In order to separate and define the fields clearly, the cells have been color coded.

Figure 3 provides an overview of the MCP16311/2 Design Analyzer.



MCP16311/2 DESIGN ANALYZER

System Parameters	**Designator**		**Units**	**Notes**
Input Voltage	E	24.0	V	$4.0V \le E \le 30.0V$
Output Voltage	U	2.0	V	$2V \le U \le 24V$
Output Current	I_O	800	mA	$0\ mA \le I_O \le 1A$
Ambient Temperature	T_A	25	°C	$-40 \le T_A \le 125$
Package Type	Pkg	MSOP		

System Components	**Designator**	**Suggested Values**	**Units**	**Adjustable Values**	**Units**
Inductance	L	10	µH	10	µH
Inductor DCR	L_{DCR}	100	mΩ	80	mΩ
Output Capacitor	C_{OUT}	20	µF	22	µF
Output Capacitor ESR	C_{ESR}	5	mΩ	10	mΩ
Compensation Components					
Top Feedback Resistor	R_{TOP}	15.0	kΩ	15.0	kΩ
Bottom Feedback Resistor	R_{BOT}	10.0	kΩ	10.0	kΩ
External Zero Capacitor	C_Z	0	pF	33	pF
Unity Gain Crossover Frequency		**43000**	Hz	**40000**	Hz
Phase Margin		**45.0**	Degrees	**52.1**	Degrees
Gain Margin		**12.4**	dB	**17.7**	dB
On-Chip Temperature	T_J	**105**	°C		

FIGURE 3: *MCP16311/2 Design Analyzer - Overview.*

System Parameters

The cells corresponding to system input parameters are marked in *green* as shown in Table 1. In this field, the user has to define the input voltage, the output voltage, the maximum output current, the ambient temperature and the desired package type. Note that the system parameters are limited to the minimum and maximum values recommended for this section.

System Components

Based on the parameters input by the user in the System Parameters field, the Design Analyzer calculates the recommended inductor, output capacitor and feedback resistor values. These are displayed in *yellow* as shown in Table 2.

Recommended Layout

Depending on the package type and ambient temperature selected by the user, the Design Analyzer will estimate the temperature of the switchers. On the right of the Design Analyzer, a typical schematic along with a recommended layout for each package type will be displayed.

Efficiency Estimation

In order for the results provided by the Design Analyzer to be as realistic as possible, the user has the choice of trying alternative component values based on the suggested values, and assessing their overall effect on the system. All efficiency and stability analysis is done depending on the user-input adjustable values to minimize errors and ensure the best possible representation of the system's performance.

For the MCP16312, the PWM-only version, the Design Analyzer estimates the efficiency over the entire load range depending on the system parameters and user-selected system components. Because the PFM behavior is affected by both input voltage and output voltage as well as output current, it is difficult to estimate efficiency when running in PFM mode.

For efficiency at low loads in the PFM region, please refer to the MCP16311/2 Data Sheet – *"30V Input, 1A Output, High-Efficiency, Integrated Synchronous Switch Step-Down Regulator"* (DS20005255).

At this point, the designer can tune the system components in order to achieve the targeted efficiency. This process is represented in Figure 4.

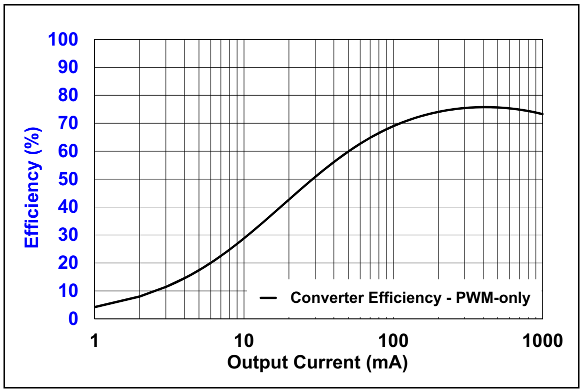


FIGURE 4: *MCP16312 - Converter Efficiency*

Note:	The efficiency estimation included in the design tool should not replace the actual measurement of the efficiency, as this might vary according to input voltages, loads, and different external conditions such as temperature.

Peak Current Mode Control Architecture

The MCP16311/2 integrates a Peak Current Mode Control Architecture, which is used to provide better response to load and line transients. Compared to the Voltage Mode Control, which uses an internal sawtooth generator, the Peak Current Mode Control uses the inductor current, which is compared to the error voltage, to form the duty cycle.

Through this control approach, the order of the system is reduced from a 2nd order to a 1st order, making the compensation much easier and the dynamic performance much better than a traditional voltage mode control.

Converter Bode Plot

The design tool provides information about the expected stability and dynamic performance of the converter through the bode plot of the closed loop system.

A bode plot is a graph of a transfer function, and it represents the magnitude (expressed in decibels) and phase (expressed in degrees) of the transfer function plotted on a logarithmic frequency scale, as shown in Figure 5.

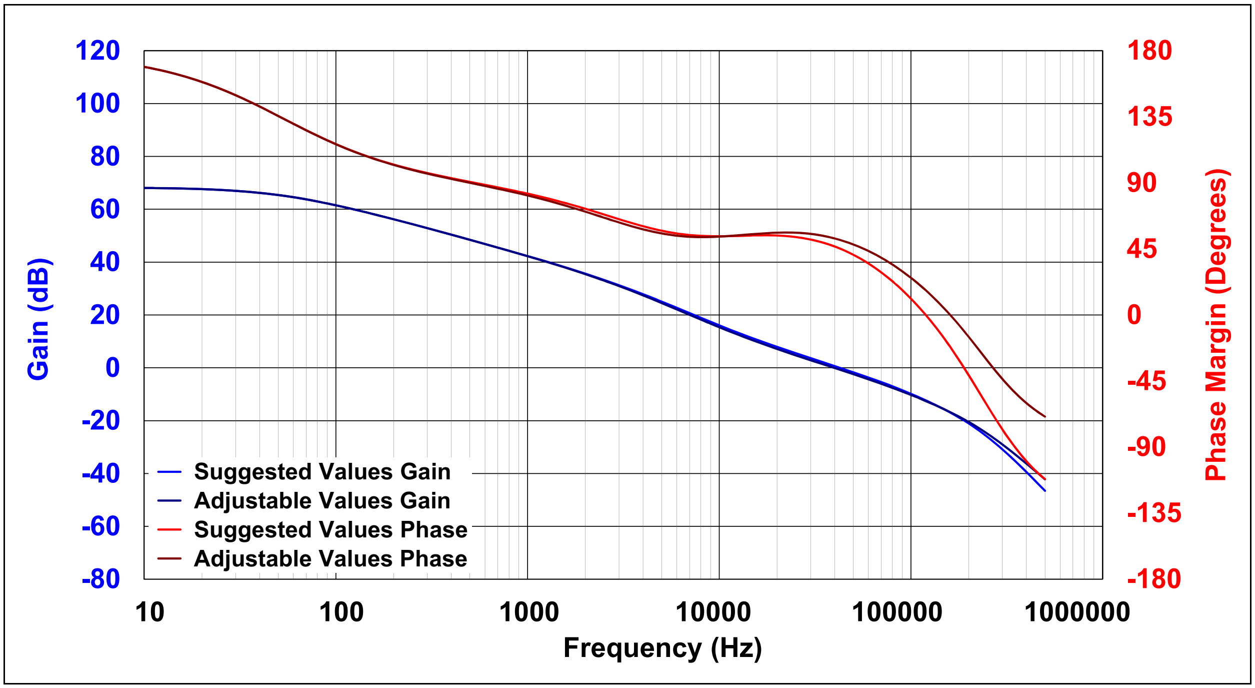


FIGURE 5: *MCP16311/2 - Converter Bode Plot.*

In order to estimate the stability and dynamic performance through the bode plots, three parameters have to be considered:

- **Crossover Frequency**: the system crossover frequency is the point where the gain of the system becomes 0 dB. A higher crossover frequency equals better dynamic performance and better transient response. However, due to possible noise issues, the crossover frequency cannot be set infinitely high.
- **Phase Margin**: in a closed-loop system that uses negative feedback, the system phase margin is defined by the difference between the phase at the crossover frequency and 0 degrees. This parameter is directly related to the stability of the closed-loop system.
- **Gain Margin**: the system gain margin is defined as the amount of gain that has to be added to the system gain to reach 0 dB, calculated at the point where the phase reaches 0 degrees. This parameter is also directly related to stability, and it indicates how far the system is from becoming unstable.

For the system to be considered stable in real-life situations where noise and high-order effects may occur, the following two conditions have to be concurrently satisfied:

- phase margin ≥ 45 degrees
- gain margin ≥ 6 dB.

The higher the value, the more stable the system is. However, by over-increasing these two parameters, the crossover frequency decreases, making the system slower and with poor dynamic response to external perturbations.

By modifying the external components (the inductor, capacitor or feedback loop), the user can tune the frequency response of the system.

STEP-BY-STEP DESIGN APPLICATION

This section presents a design example using the MCP16311/2 Design Analyzer. The required project has the following input parameters:

TABLE 1: MCP16311/2 - INPUT PARAMETERS

System Parameters	Designator	Suggested Values	Units	Notes
Input Voltage	E	24	V	4.0V ≤ E ≤ 30.0V
Output Voltage	U	2	V	2V ≤ U ≤ 24V
Output Current	I_O	800	mA	0 mA ≤ I_O ≤ 1A
Ambient Temperature	T_A	25	°C	-40 ≤ T_A ≤ 125
Package Type	Pkg	MSOP		

Based on these input parameters, the Design Analyzer calculates the recommended values of the external components for both the power train and the feedback loop. At this point, the user has the possibility to fine-tune the component values in order to get more precise results.

In this particular example, the inductor DCR and the capacitor parameter have been modified. In order to gain more phase margin, the external zero capacitor has been added, as well.

TABLE 2: MP16311/2 - SYSTEM AND COMPENSATION COMPONENTS

	Designator	Suggested Values	Adjustable Values	Units
System Components				
Inductance	L	10	10	µH
Inductor DCR	L_{DCR}	100	80	mΩ
Output Capacitor	C_{OUT}	20	22	µF
Output Capacitor ESR	C_{ESR}	5	10	mΩ
Compensation Components				
Top Feedback Resistor	R_{TOP}	15.0	15.0	kΩ
Bottom Feedback Resistor	R_{BOT}	10.0	10.0	kΩ
External Zero Capacitor	C_Z	0	33	pF

TABLE 3: MCP16311/2 - STABILITY ANALYSIS SUMMARY

Crossover Frequency	48000	40000	Hz
Phase Margin	42.2	52.1	Degrees
Gain Margin	16.9	17.7	dB
On-Chip Temperature	105		°C

Note: In the blue cells, the stability analysis summary (for both the suggested value and the adjustable value) is displayed.

CONCLUSION

The MCP16311/2 design analyzer provides the user with a tool to estimate the static and dynamic behavior of the MCP16311/2 synchronous buck converter.

By using this design tool, the engineering cost and schedule time can be reduced as the optimized final solution is reached in fewer iterations.

However, the design analyzer should not substitute proper in-system verification and validation, but rather help facilitate these processes.

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ISBN: 978-1-63277-558-0

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