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Custom Chips

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Create your own system on a chip

Make products smart and cut costs

Guard against copycat competitors

Brian Underdahl

Arm 2nd Special Edition

About Arm

Arm technology is at the heart of a computing and connectivity revolution that is transforming the way people live and businesses operate. Arm's advanced, energy-efficient processor designs are enabling the intelligence in more than 100 billion silicon chips and securely powering products from the sensor to the smartphone to the supercomputer. With more than 1,000 technology partners including the world's largest business and consumer brands, Arm is driving innovation into all areas where compute is happening — inside the chip, the network, and the cloud.

Arm DesignStart provides fast, simple, no-risk access to the world's most proven IP for no upfront fee. You can design, prototype, and commercialize a chip for $0 upfront with the widely-deployed Cortex-M0 and Cortex-M3 processors, used in more than 20 billion SoCs to date.

To find out more about the fastest route to silicon success, please visit designstart.arm.com.

Custom Chips

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Introduction

Technology-driven product and service innovations are driving new business opportunities in many different sectors. Customers expect your products to include intelligence, and you need to make sure you're staying competitive. It's vital that you understand how chip technology can play a part in making your products smart, while helping to control manufacturing costs and protect your investments.

About This Book

Custom Chips For Dummies, Arm 2nd Special Edition, introduces you to custom SoCs/ASICs (system on a chip/application-specific integrated circuits) technology, shows you some of the important benefits of this technology, and provides a high-level view of how your company can get started. You'll see why a custom SoC may be the right way to plan for future products and gain the knowledge you need to talk with suppliers, design partners, and/or your internal engineering team.

In this book, you'll see how the process of creating a custom SoC plays out, and you'll learn where to get help if you need it. You'll also find out how going the custom SoC route can help reduce BOM expenses, while helping to protect your products from copycat competitors.

Icons Used in This Book

This book uses the following icons to call your attention to information that you may find helpful in particular ways.

The information in paragraphs marked by the Remember icon is important and therefore repeated for emphasis.

Sometimes I need to introduce a bit of technical information in order to more fully explain a particular topic. You can think of the text marked with this icon as your chance to pick up a bit of jargon you can use to impress your boss in the next staff meeting.

The Tip icon indicates extra-helpful information.

Paragraphs marked with the Warning icon call attention to common pitfalls that you may encounter.

Where to Go from Here

Hey, it's your book, so dive in anywhere. No, seriously. You can thumb through the book anywhere you like, skipping around here and there. Or, you can read it straight through from front to back, if you prefer. Either way, you can set it on your shelf and go back to it at any time you want.

IN THIS CHAPTER

- Looking at a custom SoC/ASIC
- Destroying misconceptions
- Benefiting from a custom SoC
- Understanding when custom chips are the right solution

Chapter 1
Introducing Custom Chips

The demand for ever-smarter devices has manufacturers looking for ways to add new features and intelligence to their products. In the past, this typically meant designing a board that used discrete, off-the-shelf components. Today, however, many companies are turning to an alternative solution that can often be a better choice: custom chips, which can replace many of the discrete components found on a typical circuit board with a single chip. This chapter introduces you to that solution.

Understanding What a Custom SoC or ASIC Is

When we talk about custom chips, we're actually referring to a *custom system on a chip (SoC)*. Another term that's often used is *application-specific integrated circuit (ASIC)*. If you want to put a fine point on it, an ASIC is designed for a specific application, rather than a general-purpose chip, such as a microcontroller (MCU).

An SoC is a silicon chip that contains one or more processing cores, along with on-chip memory, peripherals, and various controllers. Because an SoC contains a microprocessor, as well as the other necessary components, a custom SoC greatly reduces the component count, so that the resulting circuit board is much smaller.

But don't worry — the terms ASIC and custom SoC are often used interchangeably, even by the experts!

Dispelling Misconceptions

The most common misconception about custom SoCs is that they must be far more expensive than simply designing using discrete components. In reality, because the SoC replaces so many components, your bill of materials (BOM) is typically much smaller.

Another common misconception is that a custom SoC is only for large companies with very deep pockets.

Fortunately, that isn't true, either. In fact, suppliers like Arm and its partners offer solutions that greatly reduce barriers to entry and make it possible for even small companies with low volumes to consider a custom SoC.

Considering the Benefits

Custom SoCs can offer quite a number of benefits compared to the status quo of circuit boards built with a bunch of discrete components. These benefits include:

- **Reduced BOM:** Replacing a board full of components with a single SoC means that you have fewer components overall, saving you money.
- **Lower power consumption:** This also means that your product can greatly extend its battery life.
- **Smaller size:** A single SoC is much smaller than the alternative, so products like medical wearables can be greatly slimmed down. But even products that aren't meant to be worn can benefit from having the much smaller physical size of an SoC.
- **Data security:** With many of the components integrated into a single silicon device, fewer signals are exposed to snooping eyes. This gives hackers fewer opportunities to steal sensitive data.
- **IP security:** Some companies have little or no respect for intellectual property and are quick to make copycat versions of popular products. Unfortunately, a design that uses a board

populated with off-the-shelf components is easy to copy. Using an SoC makes it much more difficult, if not impossible, to copy your product.

- **Greater functionality:** With a custom design, an SoC can offer features and functions that simply might not be achievable within design constraints using standard off-the-shelf components.
- **Supply chain protection and simplification:** With a custom SoC, you don't have to worry about components reaching end-of-life and being discontinued by your suppliers. You're protected against having to scramble to keep your product in production.

Seeing When a Custom Chip Makes Sense

A custom SoC may offer a lot of benefits, but is it the right solution for your product? Consider the following:

- Would your product benefit from smaller size, lower power consumption, and more features?
- Are you spending more than $2 million per product line on electronic components in a year?
- Can your product be copied easily?

If your answer to any of these questions is "Yes," a custom chip might be the best solution for you.

IN THIS CHAPTER

- Looking at SoCs versus off-the-shelf components
- Looking at costs
- Keeping costs in check
- Seeing how to protect your property

Chapter 2
Understanding the Economics of Custom Chips

At first, the idea of moving from the existing world of off-the-shelf components to custom SoCs may seem daunting. But, as this chapter shows you, there are many reasons why a custom SoC can make good economic sense for your company and your products.

Considering SoCs versus Off-the-Shelf Components

Traditional electronic control systems have generally consisted of discrete components attached to printed circuit boards. Those components, which you might get from a distributor, can include analog and digital sensors, logic circuits, I/O controllers, microprocessors, resistors, capacitors, and so on. Such a control board might well have considerable size and, with lots of components, many potential points of failure.

WARNING

A hidden danger that's often overlooked with off-the-shelf components is the potential that, eventually, some will be discontinued by their manufacturer. If, for example, a chip used for logic or signal processing reaches end-of-life (EoL), it may be necessary to completely redesign the circuit board using alternative components.

An SoC integrates all of the functions of the various components onto a single silicon chip. This single chip can include both analog and digital signal processing, a microprocessor, embedded control programming circuitry, radio circuitry, and any necessary output circuits.

TIP

With greatly reduced component counts, a custom SoC eliminates most potential failure points, thus making your device far more reliable.

In addition, by reducing the component count and overall board size, a custom SoC enables you to add extra functionality in a more cost-effective way. This enhanced functionality can help differentiate your product from look-alike or copycat competing products.

Looking at the Costs

A custom SoC can reduce your bill of materials (BOM) by as much as 80 percent, depending on the application. Even so, you must consider the upfront costs associated with a custom SoC. These include the cost of designing the SoC and other non-recurring engineering charges (NRE).

At this point, you may be asking yourself, "Given the higher cost, how can I ever expect to make a profit?"

REMEMBER

Reusing existing designs is not only efficient, but can greatly reduce the cost of each device. For example, there's no need for your engineers to come up with a brand-new microprocessor design to power your new product. Rather, you can use trusted and

proven designs, from companies like Arm and its partners. This enables engineers to quickly develop the custom features your product needs without worrying about the underlying processor logic. Effectively, this means that you can license and use existing Intellectual Property (IP), instead of incurring the costs of building it yourself. Some IP providers offer easy access and flexible licensing, to help you get started quickly, easily, and with much lower risk.

CASE STUDY — AUTOMOTIVE MODULE

The project is for an automotive car alarm, to replace and enhance an analog system with a high BOM with a DSP-based single chip that is programmable and flexible. Production will be in the range of 500,000 units per year.

Discrete BOM: $10.77

SoC BOM: $6.41

NRE: $1.45 million

Break-even: Only eight months of production

Reducing Your Materials Costs

It costs a lot to maintain an inventory of circuit boards and numerous discrete components, assemble all of those components onto the board, and then test the completed boards to ensure proper functionality. With a large number of components, you're also at the mercy of market forces in the event there is a shortage of any particular type of component.

By replacing an entire circuit board assembly with a single SoC, you greatly reduce your BOM as well as the risk associated with individual components. Also, assembly and testing costs become a fraction of what they were when using off-the-shelf components.

One of the key factors in reducing your materials cost is basing your design on a proven CPU, such as Arm's Cortex-M0, Cortex-M3 or Cortex-A5 processors. Processors like these are well known, inexpensive to use, and easy to program to suit your needs. If you are an embedded designer, you're probably already using them because they have been shipped in over 35 billion chips to date.

In fact, if you are already incorporating these processors in your product, you can reuse your software investment when transitioning to a custom SoC. By choosing an established IP provider, you can access a whole ecosystem

of tools, software and broad developer knowledge, as well as training, support, and resources.

A custom SoC based on an existing CPU design incorporates that CPU's silicon into the circuitry of the SoC along with the other circuits necessary to perform the functions your product needs. The custom SoC is really a complete system with the CPU, memory, I/O circuits, and various other needed parts integrated into a single chip.

Protecting Your Investment

A custom SoC can help you protect your IP by making it extremely difficult for someone to reverse engineer your products. Unlike a design using off-the-shelf components, where anyone can see which components are in use and how they're connected, a custom SoC doesn't provide any visual clues to how the circuits function. In fact, it is extremely difficult to reverse engineer an SoC.

Unscrupulous companies are always on the lookout for new products to copy. These knockoffs can be churned out quickly if your product is easy to reverse engineer.

> Preventing, or at least greatly delaying, that unfair reverse engineering can give your product a chance to become established in the marketplace, thus enabling you to recoup your development costs and make a profit.

Risks are always involved in producing and marketing any product. You need to control those risks to safeguard the future of your company. Unfortunately, every outside supplier that you deal with represents a potential risk because they could go out of business or stop producing a vital component needed for your product. Often, such events can happen without warning, leaving you scrambling trying to find another supplier or component to keep your production line moving.

A custom SoC can help you mitigate such risks because you aren't dependent on individual components that may become unavailable or on suppliers who may suddenly disappear. You own the design and control of the production of your custom SoC, so you can always be sure that you have the chips when you need them. This capability to control the lifespan of your vital components can be especially important if you operate in a market with long product life cycles, such as rail transportation, aerospace, military, and so on.

CASE STUDY — DISPOSABLE HEALTHCARE MONITORING DEVICE

The project was required to meet a "disposable" price point. With a discrete solution, it was impossible to meet power consumption and feature requirements. The device wirelessly monitors heart rate, respiration rate, and temperature for more than five days continuously.

Discrete BOM: $8.17

SoC BOM: $2.42

NRE: $2.32 million

Break-even: Only 1 million units

IN THIS CHAPTER

- Considering what you want
- Understanding the process

Chapter 3
Understanding the Steps Required

After looking at what a custom SoC is and considering some of the ways custom chips can help your company, it's time to look at what it will take to do it. This chapter takes a look at the process.

Planning Your Product

Before you can begin designing a custom SoC, you need to spend time planning for your new product. The planning stage is vital because you need to know what you want it to do, and if there are any special requirements.

The planning stage must result in well-defined and agreed-upon product specifications. Projects are often plagued with cost overruns caused by stakeholders' late spec changes. You need to give the team the opportunity to provide their input, but you also need to give them an absolute deadline for new features.

Looking at the Design Flow

Once you've defined the product specifications, you'll be able to create your list of exactly what the SoC should do. This list of functions will guide you through the design process. Here's a quick look at the steps that are involved.


TIP

Don't panic, Chapter 4 helps you understand more about the process and the type of help that's available.

SoC definition

Begin by defining the components needed in your SoC. For example, if you need wireless connectivity, the type of connectivity (such as Bluetooth, NB-IoT, or Wi-Fi) will be part of the definition. Consider also what operating system you need. A microcontroller such as Cortex-M0 can run an RTOS; if you need to run Linux, then you need to consider a more capable processor such as Cortex-A5. Further parts of the definition might include the types of sensors needed to sample analog or digital signals, I/O ports to control machine functions, and so on.

In addition to creating the hardware definition, you need to define the functionality of the software running on the SoC and how it will respond to various inputs. An example of this might be what the device should do when a temperature sensor detects a rise in temperature.

IP selection

With your definitions in place, the next step is to choose the IP. Rather than trying to develop everything from scratch, it makes sense to use designs that have been proven in existing devices. For example, Arm processors have shipped in more than 145 billion devices and are backed by a huge ecosystem of software, tools, and developers. Your choice isn't limited to processor IP; a number of providers can license the additional components you may need. The ability to use existing, well-proven components can simplify your design process, minimize risk, and bring your product to market faster.


TIP

You don't have to pay a huge fee for proven, trusted IP. Programs like Arm Flexible Access let you pay a low upfront fee to design with a range of Arm technology, and then license only what you actually use in production. Arm DesignStart even offers Cortex-M0 and Cortex-M3 technology with zero upfront license fee.

Design and integration

Processors and other system IP are typically supplied as "Soft IP," where the behavior of the IP is described using a language similar to those used in software programming. The most common for digital circuits is called Verilog.

Additional IP blocks can be created using Verilog, and it can also be used to create logic to connect the IP blocks to form a system. The system can then be simulated to check that everything performs as expected.

Computer-based Electronic Design Automation tools (EDA tools) are used throughout this process — from writing and debugging the Verilog through to the simulation, validation, and implementation stages covered in the next sections. It wouldn't be possible to create the sophisticated devices we enjoy today without the automation offered by these tools.

Verification

After completing your design, it's time to run it in the simulator. The stage where you check that what has been designed meets the specification is called *verification.* Verification is performed through simulating the completed design within a simulation tool.

The simulator enables you to check the behavior of the digital and analog sections of your design by applying virtual signals. It is important to fully validate your

design before you commit to silicon because each iteration of a test chip costs time and money.

If all of the results come out as expected, congratulations! In most cases you'll likely find that your design needs a little tweaking in order to work just the way you want it to. But that's the beauty of being able to simulate before committing to silicon.

Implementation

With testing completed, you can move on to implementation, in which you render your design in silicon.

Sometimes, companies opt to prototype the custom SoC using a *field-programmable gate array* (FPGA) before committing to creating the masks that will produce the silicon chips. An FPGA is a type of programmable chip that can be created relatively inexpensively and then used to make sure that the design works in silicon.

Once the company is ready to commit the design to silicon, the system design is mapped to the manufacturing process used to make the chip, and a layout is created. The mapping of transistors to silicon uses another form of IP called *physical IP,* but don't worry, because there are companies (like Arm) that provide this technology.

Tape-out

The transition between the design phase and the manufacturing phase is called *tape-out.* The output of this

stage contains all the necessary information for the foundry to produce the chip to your design.

The phrase tape-out harks back to the days when Internet connectivity was slow and the electronic information files that the chip fabricators needed to manufacture the chips were so large that they had to be stored and transported on physical media. That media was a tape — hence the term *tape-out*.

Production and packaging

Silicon chips are created on a large wafer made of pure silicon. Various chemical processes, analogous to printing, are used to create circuits on the silicon. The position of the circuits is determined by a set of optical masks made from the final chip layout. These masks are used in the manufacturing process to "print" the circuits onto the wafers.

A silicon wafer contains many copies of the chip. The wafer is then cut to produce the individual chips or "dies." Your custom SoC is now ready for packaging.

Depending on your needs, you may not need enough copies of the SoC to meet the minimums required by large fabricators. Fortunately, there are consolidators who combine orders from more than one customer in order to meet those minimums.

Each bare chip then has leads attached and is packaged to protect the chip.

IN THIS CHAPTER

- Finding the help you need
- Making sure you use the right IP
- Building prototypes
- Beginning production

Chapter 4
Getting Started

Getting started with custom chips may seem like a daunting prospect, so it's good to know that you aren't alone. This chapter shows you where you can turn for help and also helps to demystify the process of creating the custom SoC that will make your product stand out in the market.

Finding Help

Let's face it, not everyone is comfortable with jumping with both feet into something that seems as complex as designing a custom SoC. Sure, programs like Arm Flexible Access and DesignStart are intended to make the process

as simple and straightforward as possible, but if you've never done something like this before, you might feel reluctant to take on the task. It doesn't matter if you're a startup with little prior history of SoC design or a well-established company without in-house design capability; it's good to know that help is available. And in fact, working with a design partner is, in most cases, the right decision; why try to build up that expertise when others can do it more quickly and efficiently for you?

Arm, for example, has recruited a number of highly competent design service companies. The list of these approved partners is available to any Arm customer who needs design services. These partners receive support directly from Arm for the duration of your project.

TIP

Members of the Arm Approved design partner list are carefully vetted. They're only invited to join after having passed a strict audit, and are regularly re-audited to ensure professionalism, quality, and capability.

Deciding on In-House or Design Partner

Once you've decided that a custom SoC is right for your project, you need to determine whether to keep the project in-house or to enlist the help of a design partner. In some cases, this may be an easy choice.

If you lack the staff with the ability to handle the design process, or you simply don't want to do it yourself, your choice is simple. You'll probably want to sign up with a design partner at the beginning of your project.

On the other hand, if you have the right people but they lack experience, you might want to find a design partner willing to do a little handholding as your team builds experience and confidence. That way, it's more likely that you'll be able to handle future projects completely in-house.


TIP

Suppliers may also have a number of training resources available for use by your team. For example, Arm offers private on-site courses and private and public webinars.

Choosing the Right IP

One of the handiest things to know about creating custom SoCs is that you don't have to design everything yourself. Rather, many of the pieces are available as IP that you or your design partner can license. For example, your team doesn't need to design its own processor, but can incorporate the design of something like the Arm Cortex-M0 or Cortex-M3 into the SoC on a licensed basis.

In addition to the processor, many other components are available as IP that you can license, for example Arm Corstone foundation IP includes pre-verified, configurable and modifiable subsystems that pre-integrate the

processor and security IP with the most relevant system components. Essentially, these various components are just plugged into the design to make up the entire functional piece. As a result, designing your custom SoC is a much simpler process that comes down to programming how you want the SoC to function, rather than a process that involves creating or verifying all your own hardware elements.

WARNING

Not all IP is created equal. Before choosing which IP to use, you'll want to ask about things like the licensing costs. For example, is there an upfront fee, and what are the per-unit charges? Does the IP have a proven track record over many designs? Is the licensing vendor able to provide any technical support you may need? Is the IP flexible enough for your project? Has the IP been verified to an acceptable quality standard and will it scale for use in future projects? Is there a healthy ecosystem of tools and software out there?

Testing Prototypes

Almost everyone has encountered products that were poorly designed or that simply didn't do the task for which they were intended very efficiently. Often these types of problems are a result of inadequate testing during the prototype stage when it would still be possible to make corrections economically.

TIP

If you're building a consumer device, don't forget that most members of the public aren't engineers and don't look at the world in quite the same way as an engineer. Where an engineer might appreciate a complex technical design, consumers aren't usually as forgiving. While it's true that you need to run comprehensive technical testing on your product, it's also important to have some ordinary people try out your prototypes before you commit to high-volume production.

In designing a custom SoC, you need to incorporate several testing phases. First, the design must have thorough testing in a simulator. Obviously, you'll want to test every function of the design to make sure that it produces the expected results. In addition, it's important to see what happens when unexpected inputs are applied. It's easy to assume that people will only use a product as intended, but such an assumption is almost always incorrect.

It's also important to test for malicious inputs, as well as expected ones, because hackers deliberately use inputs that are unexpected or out of specification to see if they can get your product to misbehave in order to attack it.

After your design has been thoroughly tested, the next stage is to produce physical prototypes. You'll want to subject these prototypes to rigorous testing. Remember, it's far cheaper to find and correct errors in a prototype rather than discovering a big problem once your product has gone into mass production.

Moving into Production

With your testing complete, you're ready to move into production. This process begins with turning your custom SoC into silicon. The companies that actually create the chips from your design are called *foundries or fabs* (short for *fabricators*). The foundries use the files from the design tools to create the optical masks of the SoC which are, in turn used to make the chips.

Your design partner will be very familiar with this process, often "taping out" a chip several times a year. That means they are experts. They know exactly what the common pitfalls are and how to check for them.

Fabricators typically have a minimum run requirement that may far exceed your needs, especially if you're a startup or a small company just testing the waters. Fortunately, other companies act as brokers, combining orders from several customers to meet the minimums.

For your first prototype, you can share the wafer and costs with other companies — this is called a *multi-project wafer*. It reduces the costs to a fraction, manages risk for you, and gets you your first device quickly.

After your SoC has been produced, it's ready to be incorporated into your product. With any luck, you'll have a runaway success, and everyone involved in your company will become an overnight billionaire.

IN THIS CHAPTER

» Ten important things to remember

Chapter 5
Ten Things You Need to Know

This book has given you a quick introduction to custom chips. There's more that you'll want to know, of course, but I'll use this chapter to briefly remind you of some of the important points that you should remember:

» **It isn't as expensive as you might think:** The majority of custom SoCs don't need leading-edge IP and silicon technology. Custom SoCs can use widely available mature technology at a fraction of the cost.

And suppliers like Arm understand the flexibility needed for startups and other companies to be able to develop products with modest budgets.

- **It doesn't have to be risky:** Believe it or not, you are not the only person considering this path! These days, it is a well-trodden route for an increasing number of companies. There is a whole ecosystem of companies dedicated to helping people like you to get the device they need, with well-developed quality processes, checklists, reviews, and expertise to make sure that custom chip design is no riskier than any other electronic design project.
- **You don't have to do it all yourself:** If you need help, there are many resources available, such as online training and support engineers. And, if you need even more help, Arm has a network of approved design partners who have been vetted for their expertise and professionalism. They can provide the support you need, from design-only all the way through to managing the entire life cycle, including production and supply.
- **You can own your future:** Creating a custom SoC can help you differentiate your product in the marketplace and can also provide you with supply chain security. No longer will you have to worry about individual components becoming unavailable due to end-of-life issues. And, by using a

custom SoC rather than a more easily copied standard component-based design, you'll be protected against unscrupulous actors flooding the market with cheap copies.

- **Investing in IP can make a lot of sense:** Making your product stand out from the crowd is vital to its success. Better functionality, ease of use, and unique features can help get a product noticed. A custom SoC and the IP within it become a valuable asset to the future of your business.
- **Different requirements need different solutions:** Different types of products call for different solutions to meet specific needs. For example, a simple IoT device may need minimal processing power and extremely low power usage. On the other hand, in a smart appliance, you likely won't be as concerned with how much power the custom SoC uses as you will with providing the necessary functions and features customers expect in today's devices.
- **Upfront investment yields future dividends:** Putting in the effort and taking the time to build a custom solution not only produces a better product, but can save you money. When you go into volume production with a custom solution, those cost savings are quickly amplified, making it much easier to invest in scaling your business for success.

- **A good specification is crucial to success:** Do your planning before trying to design your custom SoC. Make sure that you've considered the entire team's input. You certainly don't want to release a product with a custom chip that's missing features that customers expect, so do your research and create a comprehensive product specification that you'll use once you reach the SoC design phase.
- **Choosing the right IP is essential:** Designing a custom SoC becomes a much simpler process when you can choose from proven IP building blocks. Don't reinvent the wheel — make your innovation additive to proven components available on the market.
- **Don't forget your tools and software:** The investment you make in software is probably bigger than in hardware, even when you design your own SoC. Being able to reuse and build on the software you've developed is vital. Wise IP selection can allow you to reuse the software from your custom SoC in your next project, even if it uses an off-the-shelf chip.

As a new wave of computing emerges, the possibilities to create and innovate are limitless. The convergence of 5G, IoT and AI/ML will bring new opportunities and capabilities to the world.

Arm Flexible Access offers subscription-based design access to a wide range of semiconductor IP technology that gives companies of all sizes the agility to thrive in this new landscape.

Learn more at arm.com/flexible-access or contact your Arm account manager

Dive into custom chips

Technology-driven product and service innovations are driving new business opportunities in many sectors. It's vital that you understand how chip technology can play a part in making your products smart, while helping to control manufacturing costs and protect your investments. This book introduces you to custom SoCs/ASICs (system on a chip/application-specific integrated circuits) technology, shows you the important benefits of this technology, and provides a high-level view of how your company can get started.

Inside...

- Move up from off-the-shelf components
- Cut manufacturing costs
- Reduce device size and power needs
- Offer greater functionality
- Protect your investment
- Simplify your supply chain

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Brian Underdahl is a well-known author and technologist who enjoys making complicated topics easy for ordinary people to understand.

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