Digital Control in Switched Mode Power Converters and FPGA-based Prototyping

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Module - 09
Digital Control Implementation using Microcontroller
Lecture - 87
Getting Started with C2000- Software and Hardware Development

Welcome everybody, today we are going to talk about the Digital Control and SMPCs and FPGA-Based Prototyping course. As a part of this, we are going to cover module 9 which is about Digital Control Implementation using Microcontrollers. My name is Aravindhan K, I am from Texas Instruments, I am going to cover today Getting Started with C2000 devices and how to work on hardware and software that comes along with these devices to enable you to build digital control applications.

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So, the concept that we are going to cover in this lecture is primarily we are going to focus on getting started with C2000. We are going to look at the C2000 ecosystem for development, and what kind of hardware and software boards are available for development. We are also going to look at how to build your digital power; so, we are going to talk about digital power SDK and power SUIT design tools. And finally, we are going to briefly touch upon the support available through the E2E forum and the C2000 Academy.

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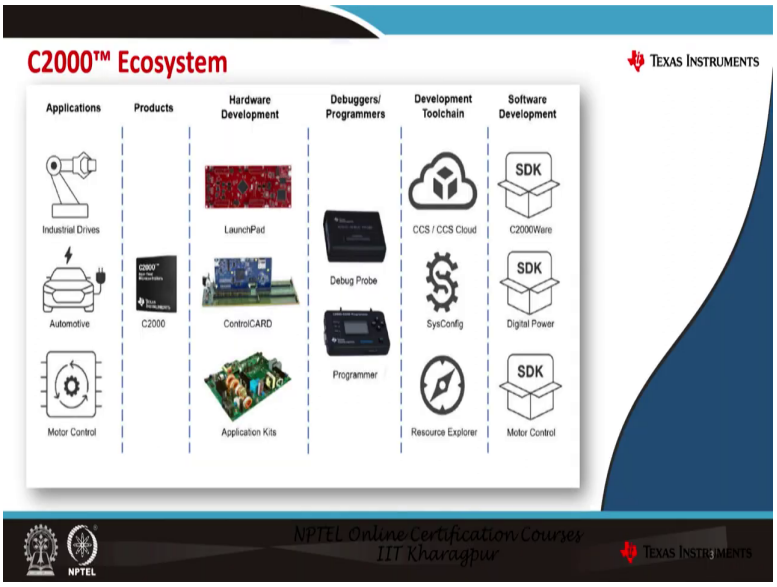

The C2000 ecosystem is very broad in the sense that along with our devices, we also provide the hardware development platform, which are the LaunchPads, control cards, and application kits. We also provide a set of debuggers and programmers to enable software development and we provide our development tools chain like the CCS SysConfig and resource explorer to create your software.

In addition to these basic software and hardware pieces we also provide software that runs on our C2000 devices; like the C2000 ware SDKs like the digital power and the motor control SDK. As you see that we have a wide range of support available to work on our device to build your end application, which could be an industrial drive automation or a motor control application.

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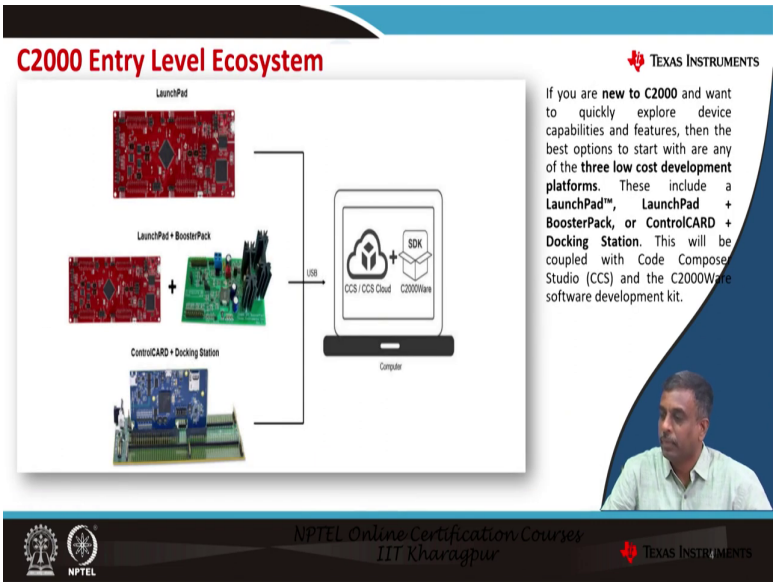

If you look at what are support available for an entry-level engineer. So, suppose you are new to C2000 and want to build quickly get an understanding of the device's capabilities, and run some of the examples and software. Then it is advised that you start with the launch pad or the LaunchPad plus BoosterPack or the control card. These three are very low-cost starting points for your hardware starting point on which you can download our C2000Ware software and start working on it to build some examples.

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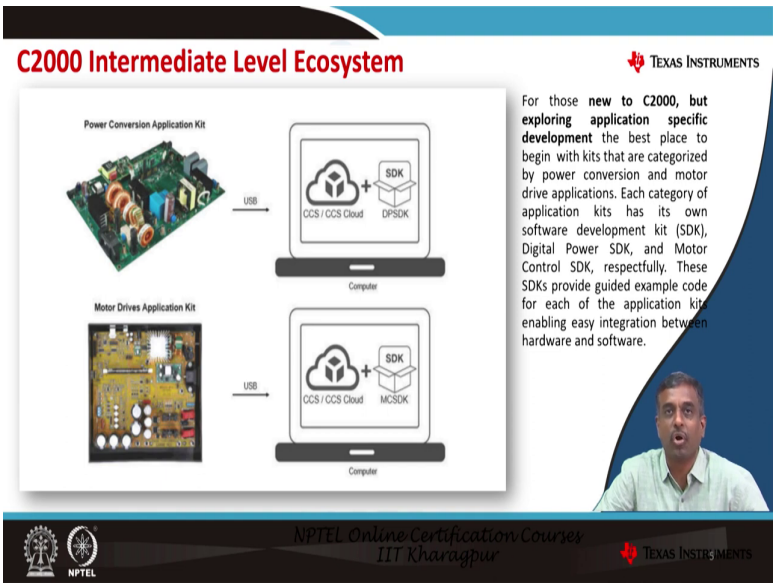

If you are an intermediate-level user you are new to C2000, but you want to explore application-specific development. Then it is best advised that you start with our SDKs, the digital power SDK, or the motor control SDK. These SDKs support large varieties of reference applications and designs that you can use the application kits and build and see them. And see how the performance of different algorithms and topologies work on our hardware.

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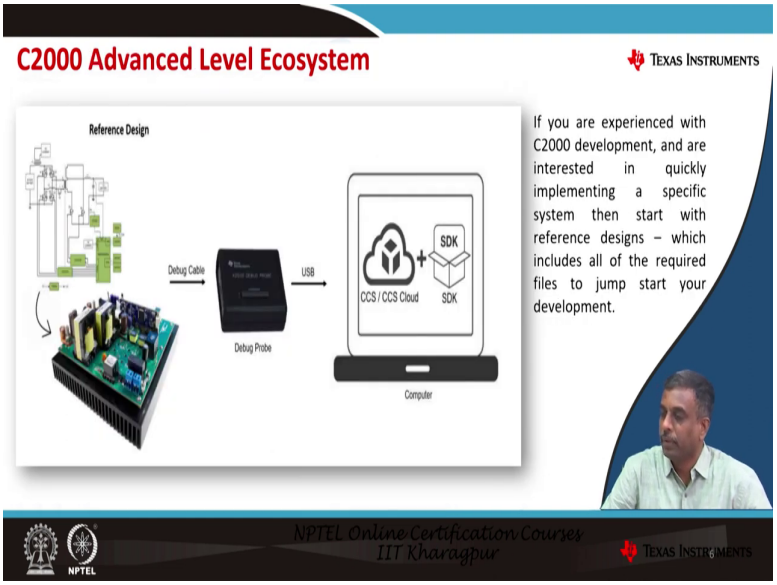

Suppose you are an advanced-level user who wants to quickly build an end application, then you should start with TI reference design. These reference designs again are supported with our software in the SDKs, using these reference designs you can see a complete application running on our custom-made hardware. Now, this will quickly help you to move toward your end application and it is a great starting point if you are interested in building a quick end application.

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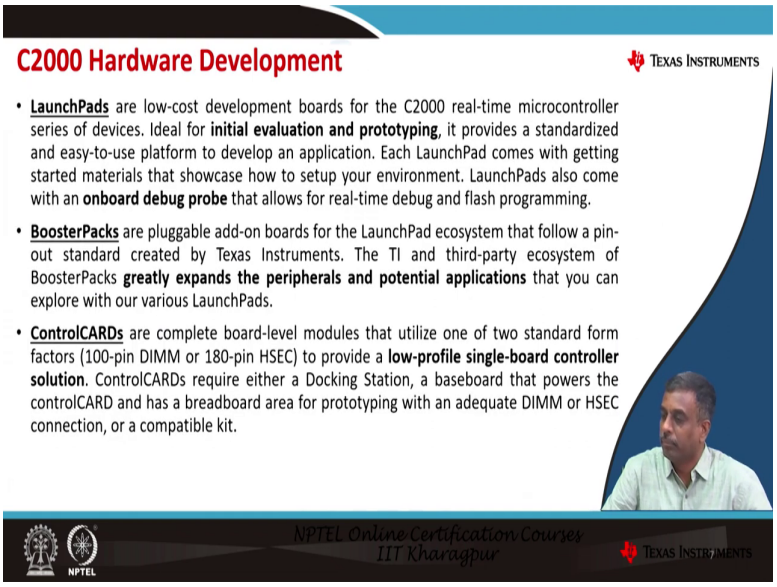

Now, we will look at each of these hardware urban platforms in a little bit more detail. The LaunchPads, LaunchPads are the low-cost development boards used for initial evaluation and prototyping. We provide a lot of software and examples to run on the LaunchPads and also the LaunchPads have onboard debug probe that allows you to do real-time debugging and flash programming.

BoosterPacks are available as add-on boards, you can add them on top of the LaunchPads, and also you can create applications that can help you to expand peripherals and potential applications that you can explore with our various LaunchPads.

The control cards are the next low-cost development platform, which provides a low-profile single-board controller solution. ControlCARDs require a docking station and a baseboard that powers the control card and also has a breadboard area for prototyping. These control cards also can help you to build an application as close as possible to the end application.

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If you look at additional support that we have; we have application kits, these kits are very much aimed at creating applications very close to the real end application. So, sometimes they are closer to the real-world power levels that you want to build; these are also good at experimentation concept education.

All application kits that we provide today have a good amount of software user guides and these are also available as part of our SDKs. The last important one that we want to touch upon is the reference design; the TI reference design is a robust design library that spans many of our processor communities. So, these are created by TI experts to help you jump-start your system design.

All the reference designs that you create today have schematics and block diagrams and design files that help you to speed up your time to market. So, if you are an advanced user and you want to build an end application, you can start with the reference design which will give you all the topologies, and different devices we are using, and also showcase actual hardware.

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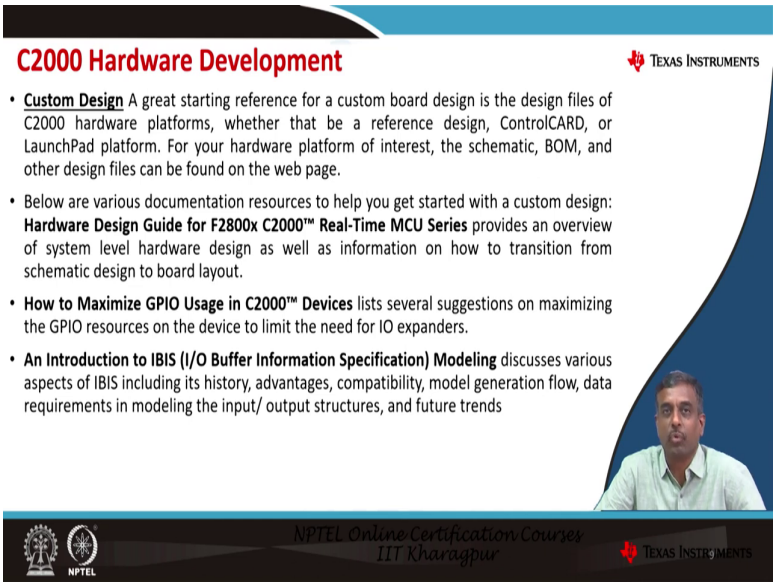

Now, let us say you want to do a custom design, if you want to do a custom design the best way is to use the design files of our hardware platforms; whether, it could be a reference design, control card, or LaunchPad. And then you can build your hardware from of interest; so, there is a lot of support available on the web to build your custom design. Today we have multiple hardware pieces along with software collaterals that help you to do this.

For example, the Hardware Design Guide for F2800x C2000 Real-Time MCU Series provides an overview of system-level hardware design as well as information on how to transition from schematic design to board layout. How to maximize GPIO Usage in C2000 Device, lists several suggestions on maximizing the GPIO resources on the device to limit the need for IO expanders. So, if you want to do a custom design, we see we suggest that you start with some of our hardware reference designs and slowly migrate them toward your requirement.

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Now, moving on to the software products that we support on our device, we have four types of SDKs. The first one is the C2000Ware which provides you with peripheral drivers, bit-field drivers, communication libraries, as well as compute libraries examples to get started tools and utilities. Several documentation is also available along with the C2000Ware. The motor control SDK is a reference for three pose three-phase motor control application.

It has the InstaSPIN FOC, FAST observer, incremental absolute encoders, and real-time connectivity examples as well. There are several examples built in this SDK using which you can build a control application. The third one is a digital power SDK which has references for digital power applications, these SDKs are primarily targeted for solar, industrial, power server, and EV charging kind of applications.

We also provide a lot of libraries and tools to help you build your digital power design, this is again built on top of the C2000Ware. The last important software piece that we provide is the safety software; this is a reference and production-ready software for functional safety. Suppose you want to meet function safety compliance, you need to run some basic software to prove your compliance.

You need to run the CPU diagnostic coverage, and the safety diagnostic library all these pieces of software are provided by TI to enable you quickly get to safety compliance either in the automotive or industrial area. So, these are four critical pieces of software that TI

provides that run on all our C2000 devices that help you to quickly jump-start your software design.

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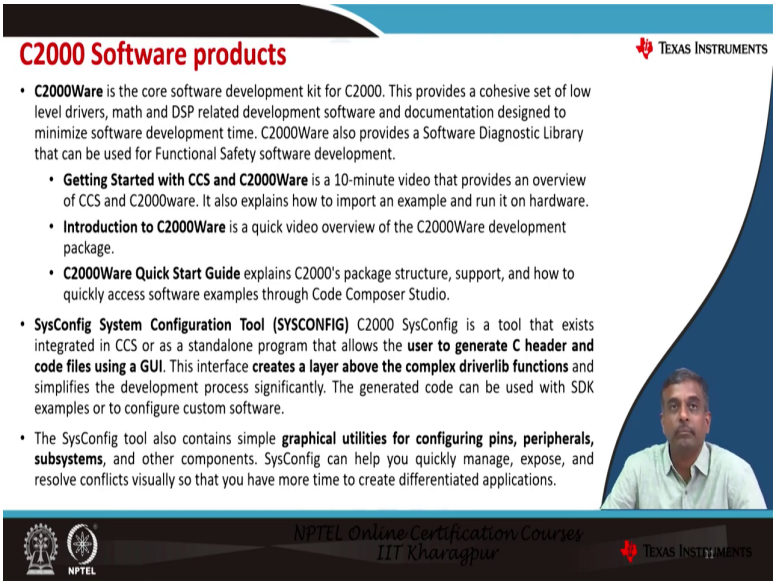

Now, let us look at some of the collaterals that we provide with all of these software products. First and foremost there is a 10-minute video that provides an overview of CCS and C2000Ware. So, this overview gives you an idea about how to get started with CCS and C2000Ware. Introduction to C2000Ware is again a quick video overview of the C2000Ware development package.

We also have a quick start guide that provides you with how to look through the package, how to look at different examples, and how to access them through Code Composer Studio. TI recently introduced a tool called SysConfig tool which helps you to build simple headers and hardware-software files that helps you to the interface on top of the DriverLib.

So, if you want to create pin configurations and configure the peripherals or subsystems you can use SysConfig to quickly generate the C and C header and C files on top of DriverLib functions. So, that we can help you quickly start enhancing the capability of the peripherals.

The SysConfig is available as part of the C2000Ware and you can load this quickly using the CCS and you can configure any of the TI peripherals. This saves a significant amount of time because you do not have to write basic drivers and also you do not have to worry about configuring them for different functionality.

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The other two SDKs that I talked about before the MCSDK and DPSDK come with the getting started guide that provides full details about how to install support, what are the different tools available, and what are the different libraries available. You can view them all through Code Composer Studio and get started building your end application.

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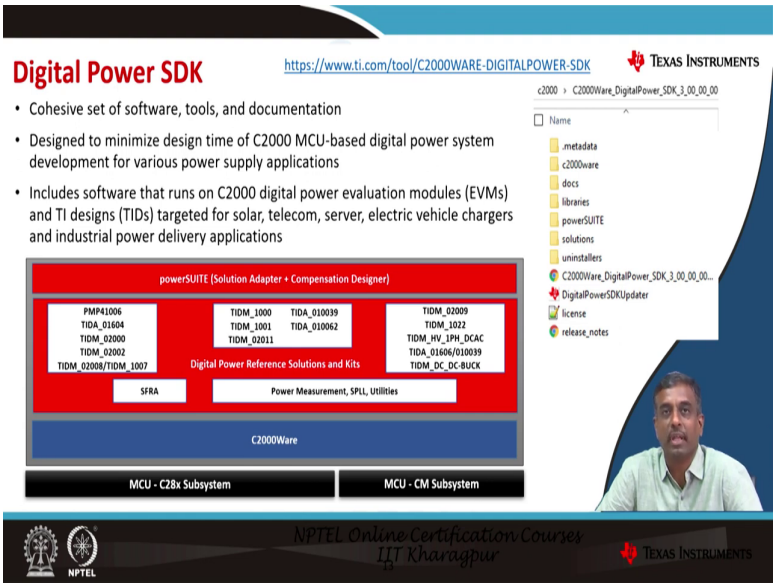

The digital power SDK is software that TI provides to help you to build quickly a digital power system. So, this SDK has several reference designs built inside, which show different topologies and capabilities of TI devices. This is built on top of the C2000Ware and on top of

this SDK we also provide what is known as a power suit which helps you to quickly build a control application. So, I will talk in detail about the reference app reference designs and the power suit in upcoming slides.

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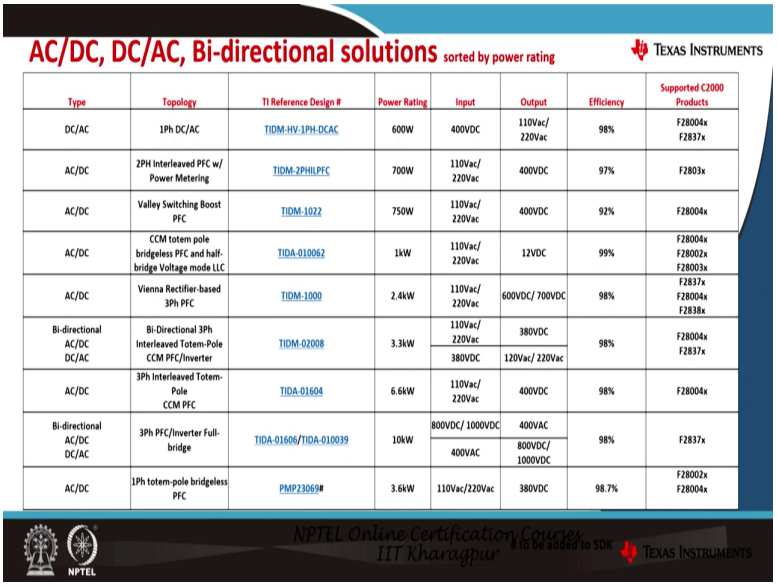

Type	Topology	TI Reference Design #	Power Rating	Input	Output	Efficiency	Supported C2000 Products
DC/AC	1Ph DC/AC	TIDM-HV-1PH-DCAC	600W	400VDC	110Vac/ 220Vac	98%	F28004x F2837x
AC/DC	2PH Interleaved PFC w/ Power Metering	TIDM-2PHILPFC	700W	110Vac/ 220Vac	400VDC	97%	F2803x
AC/DC	Valley Switching Boost PFC	TIDM-1022	750W	110Vac/ 220Vac	400VDC	92%	F28004x
AC/DC	CCM totem pole bridgeless PFC and half-bridge Voltage mode LLC	TIDA-010062	1kW	110Vac/ 220Vac	12VDC	99%	F28004x F28002x F28003x
AC/DC	Vienna Rectifier-based 3Ph PFC	TIDM-1000	2.4kW	110Vac/ 220Vac	600VDC/ 700VDC	98%	F2837x F28004x F2838x
Bi-directional AC/DC DC/AC	Bi-Directional 3Ph Interleaved Totem-Pole CCM PFC/Inverter	TIDM-02008	3.3kW	110Vac/ 220Vac	380VDC	98%	F28004x F2837x
				380VDC	120Vac/ 220Vac		
AC/DC	3Ph Interleaved Totem-Pole CCM PFC	TIDA-01604	6.6kW	110Vac/ 220Vac	400VDC	98%	F28004x
Bi-directional AC/DC DC/AC	3Ph PFC/Inverter Full-bridge	TIDA-01606/TIDA-010039	10kW	800VDC/ 1000VDC	400VAC	98%	F2837x
				400VAC	800VDC/ 1000VDC		
AC/DC	1Ph totem-pole bridgeless PFC	PMP23069#	3.6kW	110Vac/220Vac	380VDC	98.7%	F28002x F28004x

So, let us look at the reference designs that TI is providing, TI provides quite a long list of reference designs that help you to quickly start your design. So, if you look at the list of AC, DC, and DC, and AC bidirectional solutions that we have we are supporting a whole lot of topology that is available out of the box. That means, there is software and hardware available for you to do and evaluate any of these topologies.

Like, single-phase DC AC, 2-phase interleaved PFC, valley switching boost PFC, Vienna rectifiers base 3-phase PFC, and bidirectional 3-phase interleaved totem pole; so, all these topologies are covered through our reference designs. The reference design numbers are listed in the third column and if you use these names and you can go to the web and download and take a look. If you look at the power rating the reference designs range from 600 watts to 10 kilowatts.

We also show all these different reference designs on TI different C2000 TI parts. For example, if you see the last column, you can see the supported C2000 parts; this means that for each of the designs, the design has been demonstrated on the device that is listed down here. For example, single-phase DC AC is demonstrated in F28004x and F2837x. For example, if you take another design bidirectional 3-phase interleaved totem pole TIDM

02008 it is demonstrated on F28004x and F2837x. we will cover briefly this design in the upcoming lecture.

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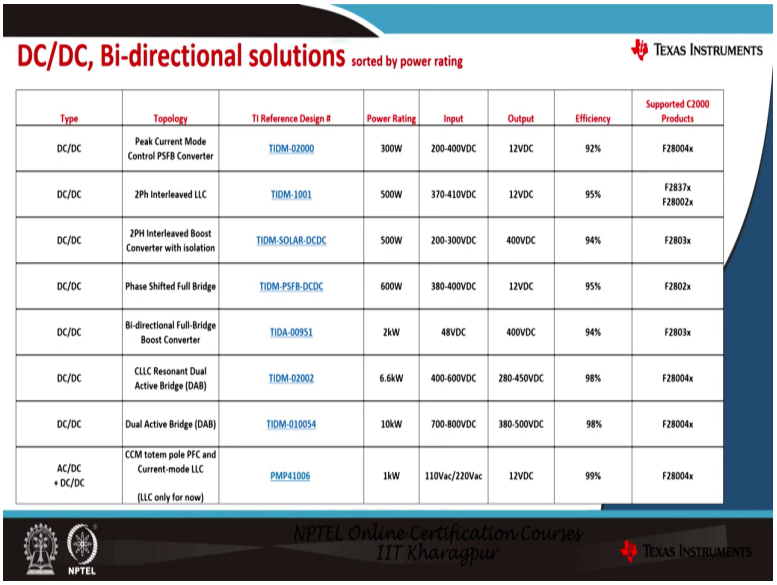

Type	Topology	TI Reference Design #	Power Rating	Input	Output	Efficiency	Supported C2000 Products
DC/DC	Peak Current Mode Control PSFB Converter	TIDM-02000	300W	200-400VDC	12VDC	92%	F28004x
DC/DC	2Ph Interleaved LLC	TIDM-1001	500W	370-410VDC	12VDC	95%	F2837x F28002x
DC/DC	2PH Interleaved Boost Converter with isolation	TIDM-SOLAR-DCDC	500W	200-300VDC	400VDC	94%	F2803x
DC/DC	Phase Shifted Full Bridge	TIDM-PSFB-DCDC	600W	380-400VDC	12VDC	95%	F2802x
DC/DC	Bi-directional Full-Bridge Boost Converter	TIDA-00951	2kW	48VDC	400VDC	94%	F2803x
DC/DC	CLLC Resonant Dual Active Bridge (DAB)	TIDM-02002	6.6kW	400-600VDC	280-450VDC	98%	F28004x
DC/DC	Dual Active Bridge (DAB)	TIDM-010054	10kW	700-800VDC	380-500VDC	98%	F28004x
AC/DC + DC/DC	CCM totem pole PFC and Current-mode LLC (LLC only for now)	PMP41006	1kW	110Vac/220Vac	12VDC	99%	F28004x

Now, if you look at the DC-DC bidirectional solutions that TI is providing, again we are supporting a whole lot of topologies and showcasing this on multiple devices. For example, peak current mode control, 2-phase interleaved LLC, phase shifted full bridge, bidirectional full bridge, boost converter, and so on. So, we have multiple topologies, which are again demonstrated on multiple TI parts. Again, the reference design numbers are listed in the third column and the power ratings, in this case, range from 300 watts to 10 kilowatts, the devices are listed in the last column.

So, if you can see that we are providing multiple reference designs on multiple TI parts; so, you can quickly get started with your design. Let us say you are creating a topology or design very close to one of these. You can use the TI reference design as a starting point which will save you a significant amount of time in building your hardware and software.

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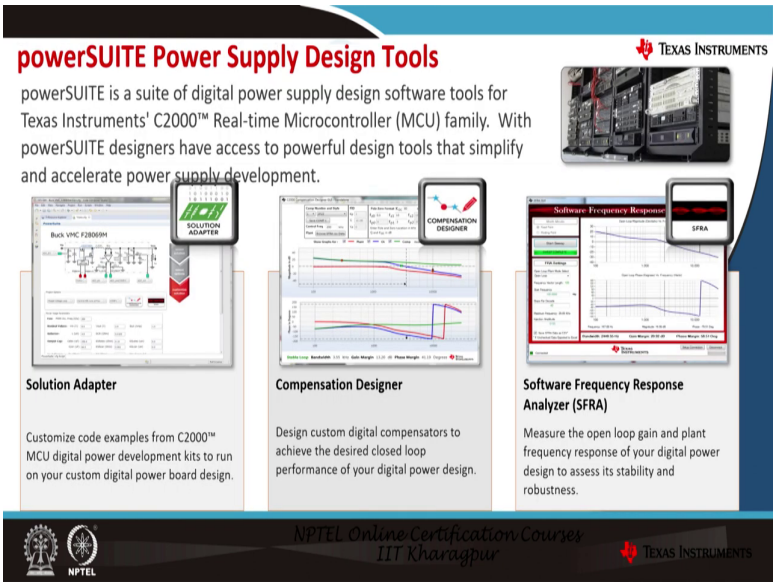

Now, let us look at some of the powerful tools that TI is giving for digital power supply design. So, for example, we have the power suit which consists of a solution adapter, compensation designer, designer, and software frequency response analyzer. The solution adapter is nothing but it helps you to customize the code examples from C2000 our development kits to run on your custom digital power board design.

The compensation designer helps you to design custom digital compensators to achieve the desired closed-loop performance. The SFRA or the software frequency response analyzer helps you to measure the open loop gain and plant frequency response of your digital filter design power design to assess its stability and robustness. The power suit is a powerful set of tools, which helps you to quickly jump start on your design.

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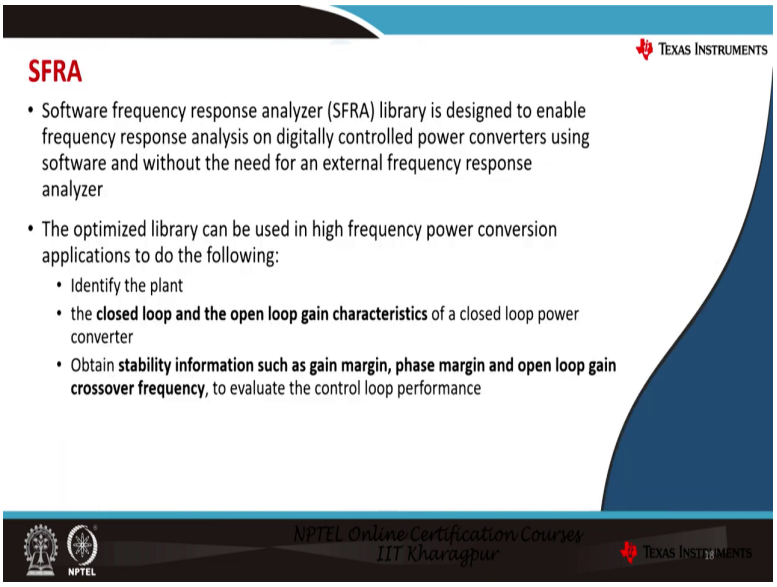

Now, if you look at what SFRA can do? SFRA is simply an optimized library that can be used in high-frequency power conversion applications. It can identify the plant, it can do the closed loop and open loop gain characterization, it can give you the stability information such as gain margin, phase margin, and open loop, crossover frequency. You can use the SRFA tool to fine-tune your digital power application.

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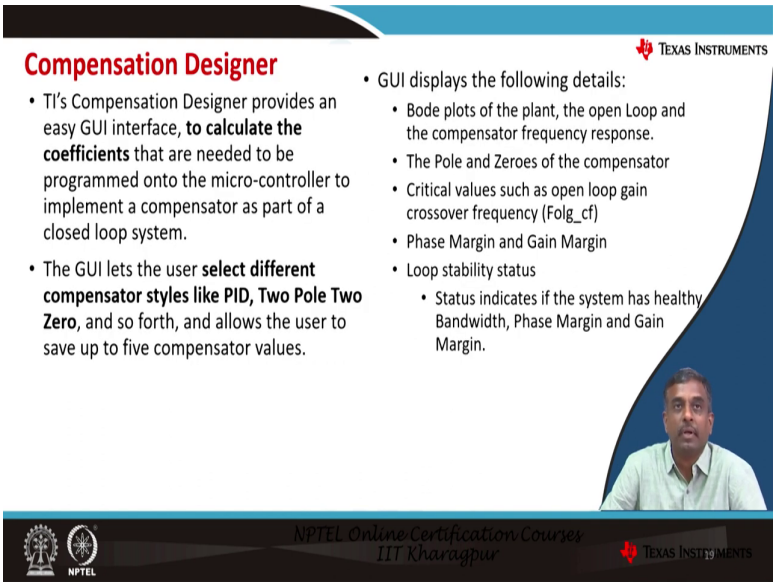

Now, let us look at what is the compensation designer. A compensation designer is a simple GUI to help you to calculate coefficients that are needed to be programmed into the

microcontroller to implement a compensator. So, GUI allows you to select different types of compensators like PID, Two Pole Two Zero, and so forth and allows users to say up to 5 composited values.

The GUI also displays the bode plot, the pole, and zeros of the compensator, and critical values such as open loop gain cross-over frequency, phase margin, and gain margin. We can also look at the loop stability status, the status indicates whether the system has a healthy bandwidth phase margin and gain margin.

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So, this is a pictorial view of how the composer looks and you can see that we can see the magnitude and the phase; also, we can see whether this loop is stable we can see the gain margin phase margin. We can also choose the type of compositor we want and also this helps you to quickly retuned your algorithm and rerun it again and again and check your stability. So, I will now show you an overall flow of how you use all these tools for your digital power design.

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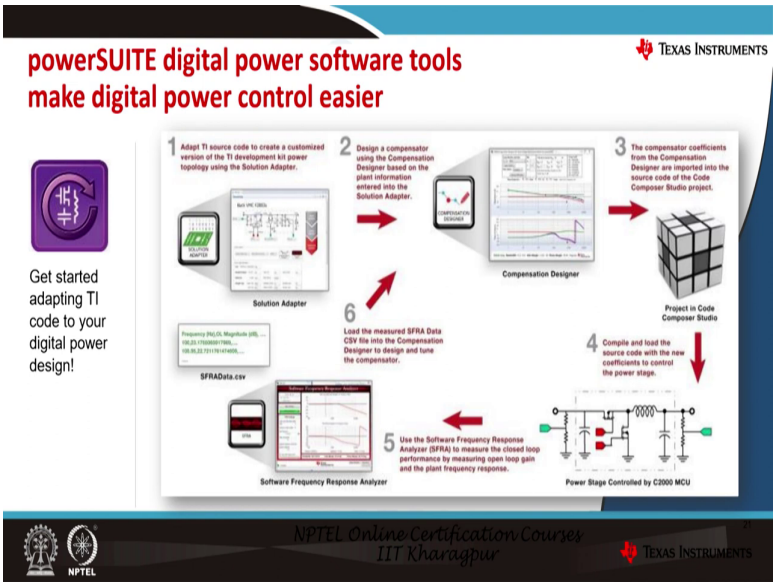

So, this is how you actually start, first you use the solution adapter; so, you use the solution adapter to adapt the code which is software that is provided by TI to your hardware. Next is to use the composition designer; so, you design a compositor choosing the compensation designer based on the plant information entered in the solution adapter.

Once you have the coefficients, use the coefficients and incorporate them into your source code and build your code using Code Composer Studio. Once you have built your code you can now load it and run it and check the performance using the software frequency response analyzer. So, using the software frequency response analyzer you can now measure the closed-loop performance by measuring the open-loop gain and the frequency response.

Again, after doing this step 5, you can now do is load the measured SFRA data again into the composition designer to design again and further tune your application. So, this way iteratively you will be able to reach a stable control loop algorithm. So, this gives a brief overview of how quickly you can start your digital power design.

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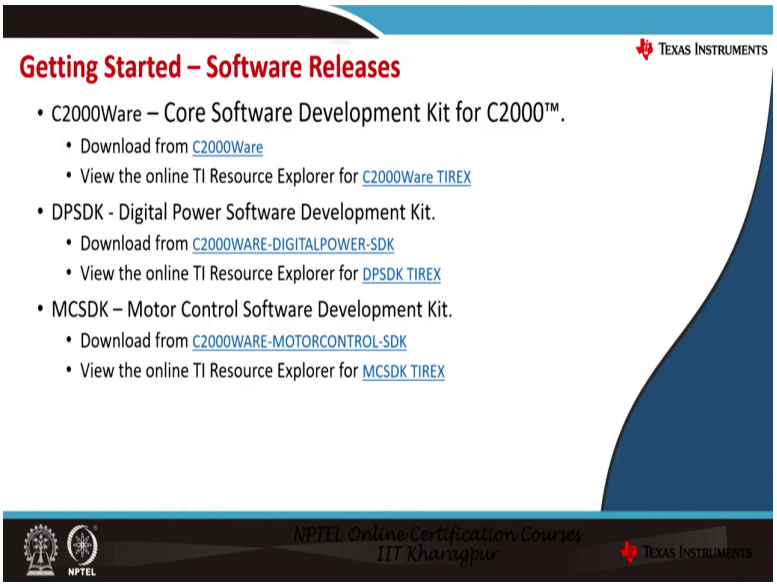

Now, along with all this software significant amount of collaterals are provided by TI to get you started. First, the places to download our software are listed here, you need to download the C2000Ware from TI's website. The digital power software SDK and motor control SDK are all freely available and you can use links the provided here to download them for your use.

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Now, in terms of documentation significant amount of documentation also is given, and the best way to start is using the getting started with C2000 software. You can get an overview of

the software development and various software available using this software guide. Next is to use the software development and optimization guide, which helps you how to use the compiler and how to each performance.

The other two significant pieces of collaterals that we have are this control law accelerator software development kit and the development guide which helps you how to write a program and run it on the CLA. And the multicore software development guide, which is useful for you to create software when we have multiple cores on our C2000 devices.

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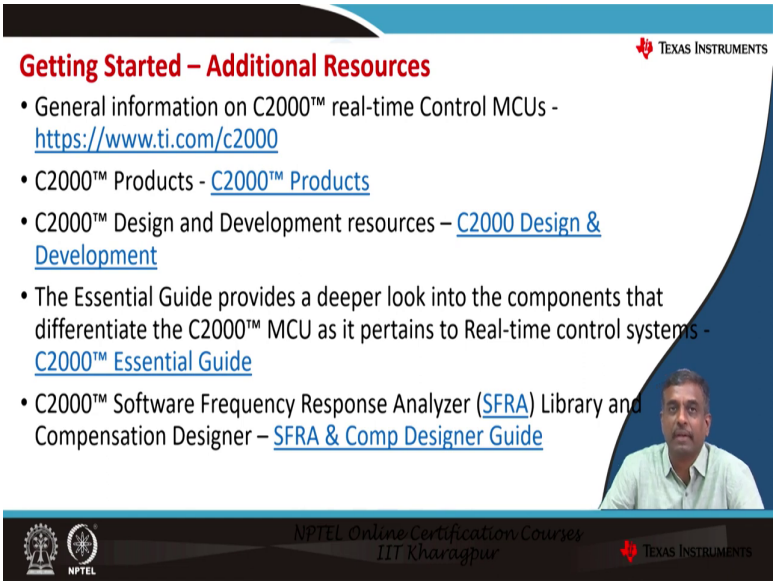

Additional available resources are very plenty; for example, we have detailed documentation on the SFRA library and composition designer. We also have a lot of details about our products on www dot ti dot com slash c2000. We also have an essential guide that provides a deeper look into the components that differentiate C2000 MCU as it pertains to real-time control systems this is called the C2000 Essential Guide.

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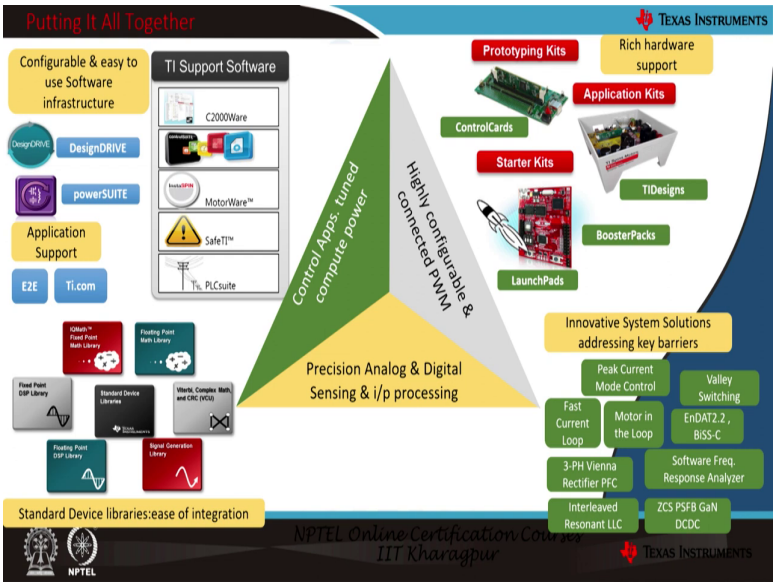

Now, if you look at our C2000 device we provide one of the best computing power in terms of processing power. We have highly configurable and connected PWN, our ADC is highly precise and powerful in terms of sense. Along with this good capability that we have in our device, we also provide a whole bunch of software that helps you to quickly jump start and do your end application building.

We talked about the C2000 ware, SDKs, and power suit which provide you with substantial software support to get started on your software journey. In terms of hardware, we do provide a lot of hardware support in terms of the Starter Kits, LaunchPads, BoosterPack s, and control cards which help you to explore the software and run it and check your algorithm and software.

And also, additionally, TI provides several reference designs addressing key concerns and helps in end application building. For example, we provide reference designs that chose peak current mode control, 3-phase Vienna rectifiers PFC, interleaved resonantly, and LLC. So, all these reference designs help you to look at what are the key system solutions and how to address the key barriers using our device.

Then we also provide substantial levels of libraries that are highly optimized, we provide the floating point unit library, the IQmath library, and the Viterbi libraries, which will help you to further accelerate the computing power. On top of all of this TI has excellent support through

the E2E and Ti dot com web pages. So, this overall infrastructure of the ecosystem of TI helps you to build your application much faster on a C2000 device.

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As a part of this course, we learned about how to get started on C2000, what are the hardware and software resources available, how to use the reference design, and how to do a digital power design. Now, you also can go to C2000 Academy for understanding many of our peripherals and software and training available. And for support, you can go to the E2E forum for help and support on the C2000 microcontroller.

Thank you.