Introduction to Embedded System Design
Professor Dhananjay V. Gadre (NSUT) & Badri Subudhi
Indian Institute of Technology, Jammu
Lecture 11
Introduction to MSP430

Hello, Welcome to a new lecture on this online course on Introduction to Embedded System Design. I am your instructor, Dhananjay Gadre. Today, we are going to start our discussions on the most important building block of out of our six box model, which is the embedded computer block. And today we are starting real discussions on MSP430 microcontroller. MSP430 is a entry level microcontroller from Texas Instruments. It is one of their oldest offerings as far as microcontrollers are concerned.

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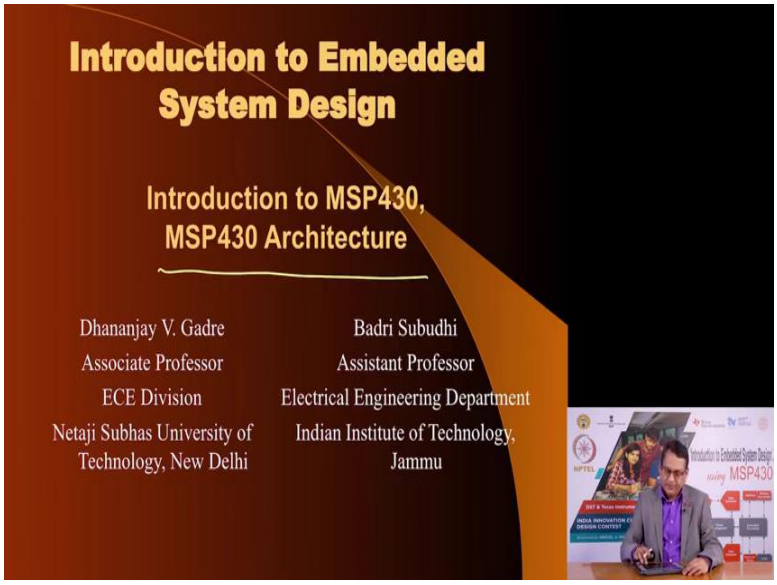

So, here is the we are going to talk about the introduction to MSP430 and subsequently we will cover the architecture.

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MSP, as I mentioned MSP430, is a microcontroller from Texas Instruments, it is one of the simple microcontroller families from TI. MSP stands for mixed signal processor. This is to indicate that the microcontroller has a CPU and another digital building blocks. And apart from that, it has support for analogue circuits and that is the reason why it is called mixed signal. It is a 16 bit processor, so if we go back to our discussion on various classification methodologies that we have that we have discussed.

From the point of view of bit handling capacity, it is a 16 bit processor, as you see here the 16 bit data path which connects to the memory which is integrated on the chip. The amount of memory and peripherals and various types of memory, in fact, can be accessed using a address bus, which is for most cases 16 bit address bus which means it has 2 rest to power 16 address locations, memory locations. And in some cases, when you want to have more memory than is possible with 2 rest to power 16 combinations, it also uses a 20 bit address bus. The data bus is 16 bits. This processor has been designed specifically for low power applications.

The intended application areas of general-purpose sensing and measurement, so you may create instruments where you sense various physical parameters, measure them, process them and provide an appropriate output. It has a concept called capacitive touch sensing you may correlate

with that very easily, because these days smartphones come with the touch and the kind of touch that is used on smartphones these days is a capacitive touch.

And so almost all the pins are a lot of pins of MSP430 microcontroller have a capability to be sensed using the capacity of touch sensing. It can also be used for ultrasonic sensing, ultrasonics are frequencies about 20 kilohertz. So, it has special support for creating waveforms so that you can operate in the ultrasonic range.

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This series MSP430 was initially launched in 1993 and in 1997, it was released to the entire world. Like we mentioned, typically a microcontroller family would have a lot of offerings so that an end application could use an appropriate device, which is optimal for that application. And so MSP430 has more than 500 different microcontrollers.

These include from the point of view of capabilities, what kind of hardware support a microcontroller has, the amount of memory it has, and also the physical footprint, small chip and big chips and so on. MSP430 series supports a low power operation. And to support that low power operation, it has 5 low power modes.

You would recall an earlier discussion where we talked of operating modes of a microcontroller and we are broadly used three terms active mode, sleep and power down. The sleep mode of

operation here refers to these five modes of low power operation and will see the details of these operations.

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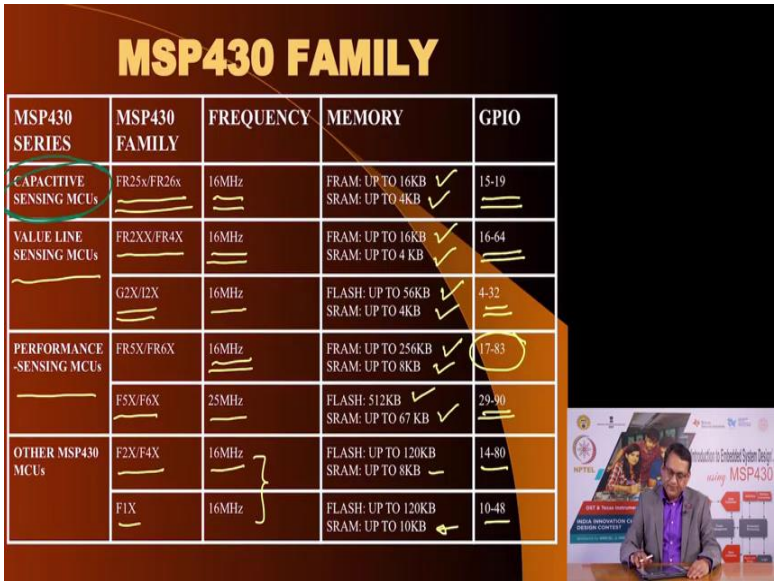

Here is a snapshot which captures almost all the microcontrollers available in the MSP430 family, you have the capacitive sensing MCU here this one.

And it has the nomenclature uses these numbers, the maximum frequency operation of members of this family is 16 megahertz and it has FRAM for the program memory and you can have up to 16 kilobytes of programmed memory. And SRAM for storing data, you can have up to four kilobytes. And the number of input output general-purpose input output pins that are available in this segment, you can have from 15 to 19 GPIO pins.

Then, we have what they call as value line microcontroller units, which means one can expect them to be very inexpensive. They have two series for that, one is a FR2xx and the other one is G2 series. The first series again can be operated up to 16 megahertz. It has FRAM up to 16 kilobytes and SRAM up to 4 kilobytes. And the number of GPIO pins as you see, is much larger from 16 to 64 pins you can have so you can expect that the packaging for this line of microcontrollers would be large and the G series and incidentally, we are going to use in our experimentation we are going to use G series of microcontrollers.

They can also operate up to 16 megahertz. They do not have FRAMs, instead, they have flash memory and you can have up to 56 kilobytes of flash memory and up to 4 kilobytes of SRAM. And the number of input output pins available in this series you can have from 4 pins to 32 pins. Then, we have what they call as performance sensing MCUs. And you have FR5 and F5x series. The first one has a maximum frequency up to, again, 16 megahertz. It offers flash memory. It offers FRAM for program memory up to 256 kilobytes.

And you see the moment this number is above 64k that means it would be using address bus, which is the 20 bit address bus. It has SRAM up to 8 kilobytes and the number of IO pins is large from 17 to 83 pins you can have. The second series the 5F6X operates up to 25 megahertz and it has flash memory, not FRAM for the program memory. And you can have up to 512 kilobytes it has SRAM up to 67 kilobytes. So, it is a huge amount of ram that is available and the number of input output pins is again large 29 to 90 pins you can have.

And then you have what is called as other MSP430 MCUs. They have two series F2 F4X and F1X and the first one, both of them actually have a 16 megahertz clock, both of them offer flash memory. And a number of IO pins is for the first one 14 to 80 and the other one is 10 to 48. And the SRAM in the first case is 8 kilobytes and here you have slightly more at 10 kilobytes. So, this single table in a way captures the kind of variety that is available in the MSP430 family of microcontrollers.

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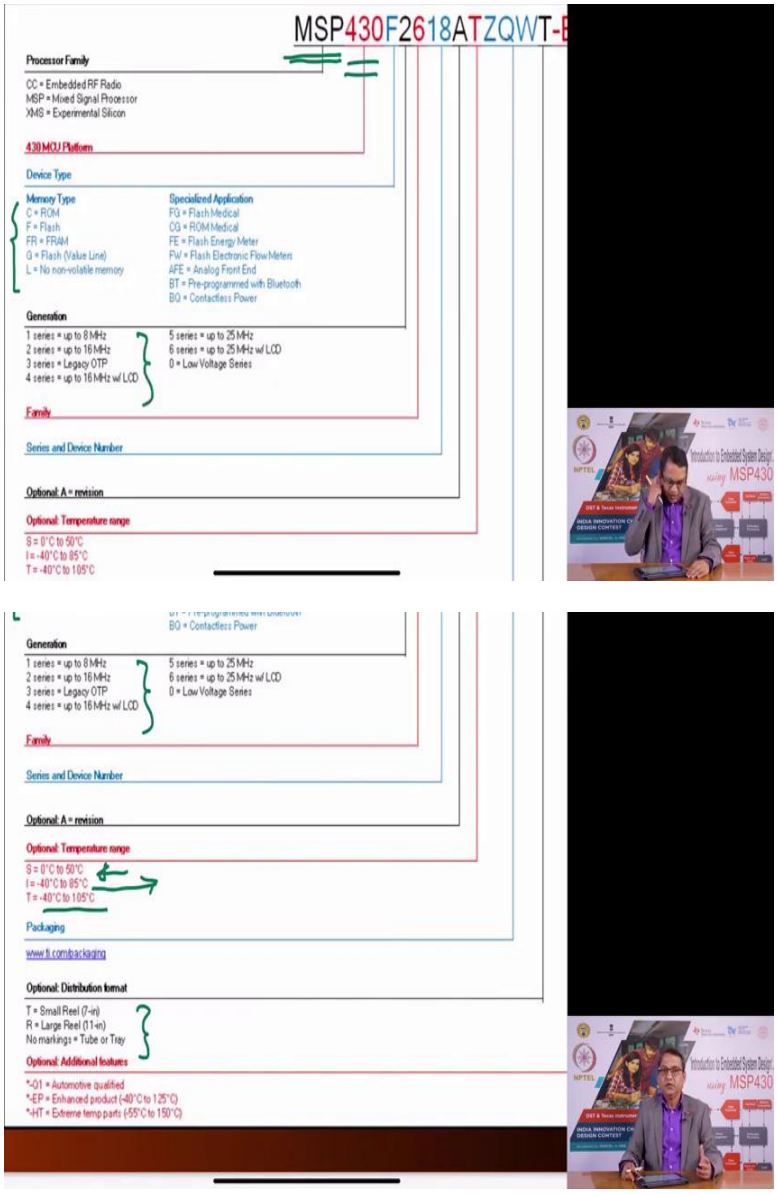

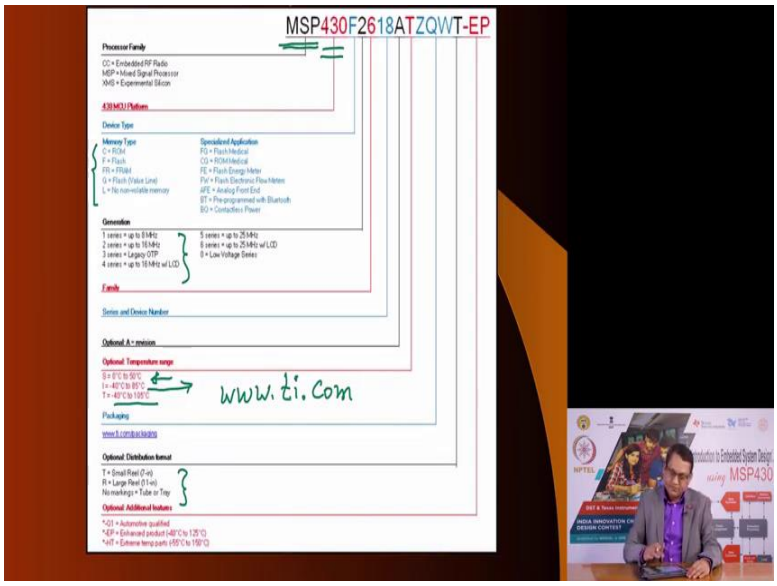

Let us see some of the more features of this family. Before that, here is a nomenclature. Let me see if I can zoom it. So, you would see these microcontrollers would be available starting with this number MSP and then 430, because there is a 430 platform the next number or numeral used is which indicates the kind of memory that is available. So, if it is F that means it is flash, if it is G, then also it is flash. If it is F.R that means the microcontroller would have a FRAM memory and so on. And then the other two next digit tells you what kind of frequency operation it offers and so on.

At the bottom it also has a variety in terms of the temperature range for which these microcontrollers are guaranteed to operate. And we have three temperature ranges. The standard one is 0 to 50 degrees. Then you have industrial range, which is minus 40 to 85 degrees, and then the extended range, which is minus 40 degrees to 100 plus 105 degrees centigrade. And of course, the packaging, the overall packaging is in the form of small or large reels or you could get these ICs in the cube form also.

And this is important information when you are doing mask manufacturing certain manufacturing equipment requires the components to be housed in a reel certain other manufacturing techniques, require them to be in a tube or even tray and so on. So, this sort of gives you an idea of how to interpret the complete part number for this series of microcontrollers. When you go to the Texas Instruments website, which is incidentally

www.ti.com, you could search for MSP430 microcontrollers and you would get to know more details about this.

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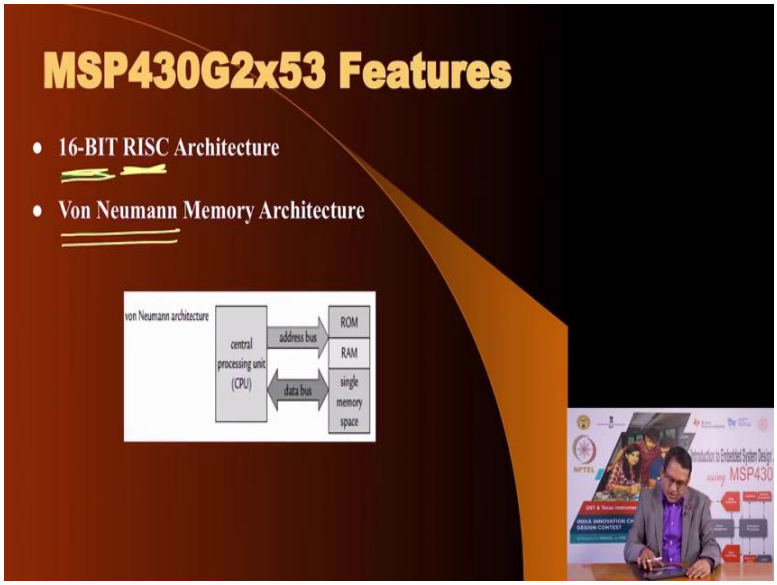

So, the important feature is that it is a 16 bit risk architecture, it is a risk architecture. So, risk indicates that the instruction set architecture is of the risk variety reduced instructions at computer and from the memory interface point of view, it is a Von Neumann memory architecture. Here, it what this indicates is that the program memory, the data memory and the registers they are all mapped into a single memory map, as you see here.

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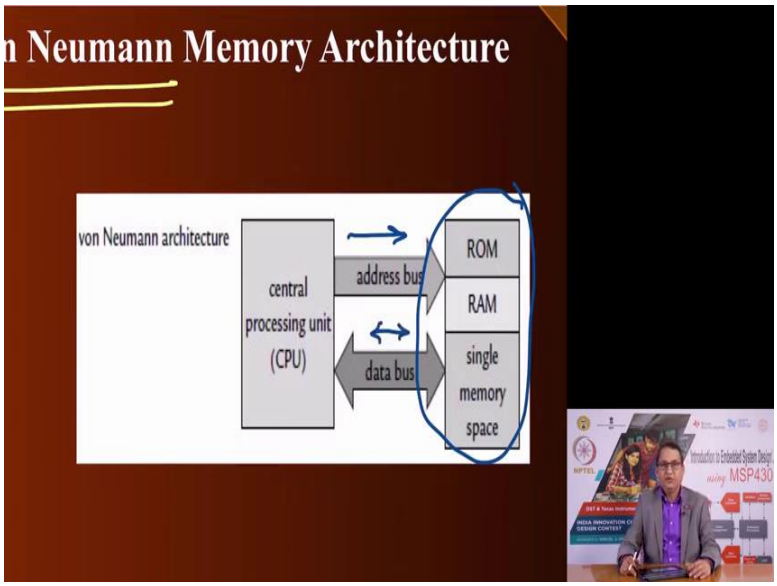

This is the memory map, and in a single memory map, using a single set of address bus here and a single set of data bus, you are able to access the ROM, which is the program memory, the RAM and the registers and so on and so forth. So, this is to highlight the nature of MSP430 microcontroller family.

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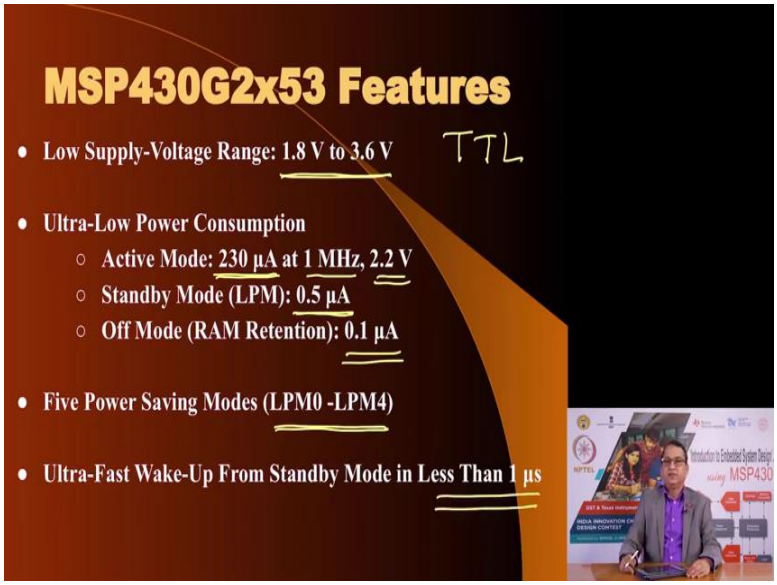

These are the features, the supply voltage unlike the microcontrollers of previous era, where they would operate at standard 5 volts.

You may also remember that TTL ICs transistor transistor logic ICs operated at 5 volts but as the frequency operation increased, continuing to use a higher supply voltage led to higher power dissipation and one way to reduce power dissipation would be to reduce the supply voltage. And so MSP430, since it is it calls itself a low power microcontroller family. Therefore, one way to reduce the power dissipation is to reduce the power supply voltage. And here you can operate it in a wide range of voltage between 1.8 volts to 3.6 volts.

This makes it very easy to operate from a battery of various types and we will see all kinds of batteries we could use. The low power consumption numbers are mentioned here in the next part. In the active mode, it only consumes 0.23 milli amperes to 30 micro amperes of current. And that happens when you operate it at one megahertz clock and the supply voltage is 2.2 volt if you operate it in a what is called a standby mode, which is one of the low power modes that is available, it consumes a mere 0.5 micro ampere of current.

And you can imagine that if you have a coin cell or a button cell, even on the single button cell for how long this microcontroller can continue to operate, provided it has large periods of time when it is in the standby mode. But once in a while it would wake up and do real work and then go back to the standby mode. If you want to turn the internal operations off and just retain the contents of the RAM, then the power consumption will go down to 100 nano amperes. That is 0.1 micro amperes that is a really low current.

It offers a variety of low power operating modes, five low power operating modes that can be selected by the user through appropriate program, executing certain instructions. And you can go from low power mode 0 to low power mode 4. While you are in one of these low power modes. And if you want to go get back to the active mode, you do not want to waste time doing that switching.

And in this case you can get back to active mode in less than one microsecond. So, these are very important and salient features of MSP430 microcontroller family.

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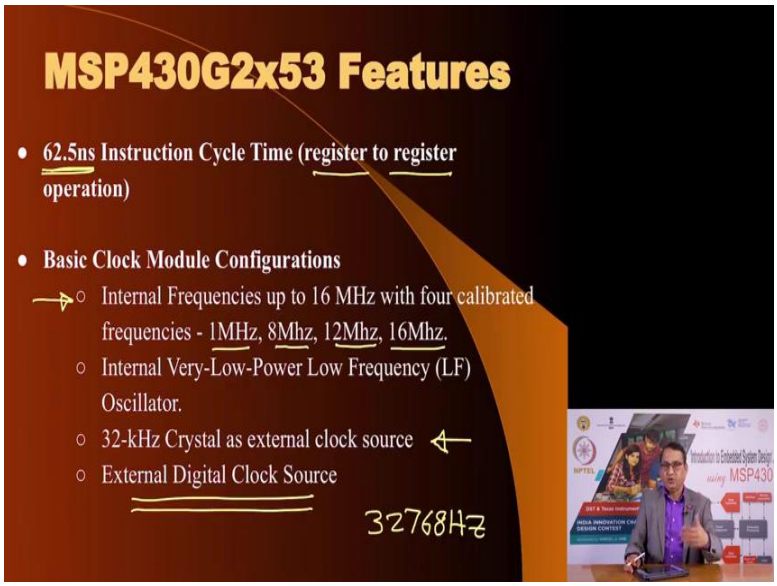

The you can, as you noticed in that earlier slide that the dominant frequency operation is 16 megahertz, so if you operated your microcontroller at 16 megahertz, the clock period will be 62.5 nanoseconds.

And in one clock cycle, you can execute instructions which would transfer data from a register to register. Of course, other instructions would take more clock cycles and therefore they would be taking more time. But this is the fastest instruction that you can execute on MSP430 microcontroller. The internal clock generator, which could take inputs from external pins, we will see which are those pins or you could utilize internal RC oscillators offer a wide variety of options.

One of them is you can have calibrated internal frequencies up to 16 megahertz, and you can choose whether you want to operate at 1 megahertz or you can want to operate at 8 or 12 or 16 megahertz. It also has internal, very low frequency oscillator, up to 12 kilohertz. And this is a very, very small frequency. And in case you do not have much computational activities to perform, you could switch yourself into low frequency, which will reduce your power dissipation.

You can use an external 32 kilohertz. 32 is exactly the 32768 hertz that I had mentioned. This kind of RTC crystal could be used as an external clock source, or you can have externally

generated digital clock source. You can apply to MSP430 as a source of clock, which could be internally utilised. And so and you can change the clock frequency. What we had mentioned, one of the salient features of contemporary microcontrollers is the ability to scale the clock frequency of operation. MSP430 has that feature.

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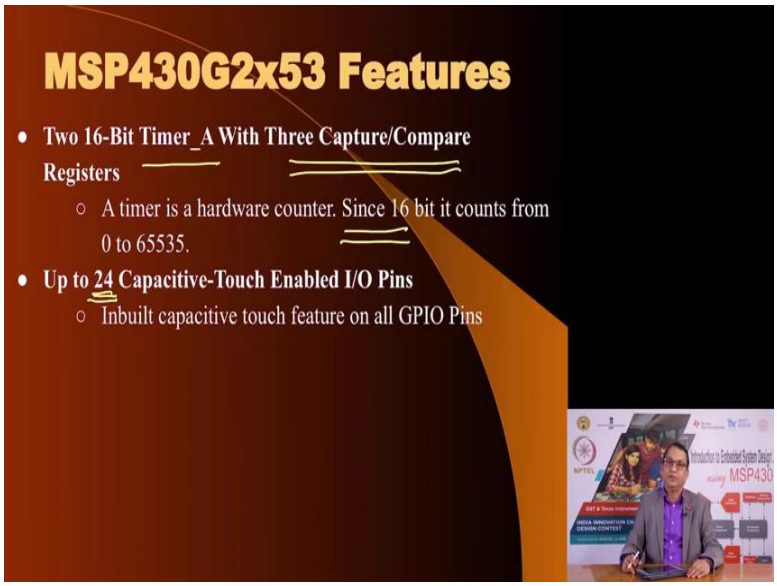

Now for the input output it offers you two timers they are referred to as timer A and it has three captured compare units. These are requirements of a timer that if you want to say how much time has elapsed, how much time has elapsed, has no meaning. But the way it is interpreted, it is that you when the clock clocks the counter, it starts incrementing and when that value is equal to certain compare register value, then you say this much time has elapsed.

So, it has three compare capture registers with which you can do variety of things. The counter these timers are 16 bit and therefore they can count from 0 to 65535. That is the dynamic range of these timers and counters. It also have up to 24 pins, which have capacitive touch enabled capabilities, and all the GPIO pins could be utilized for that, this is a very important feature of MSP430 microcontrollers.

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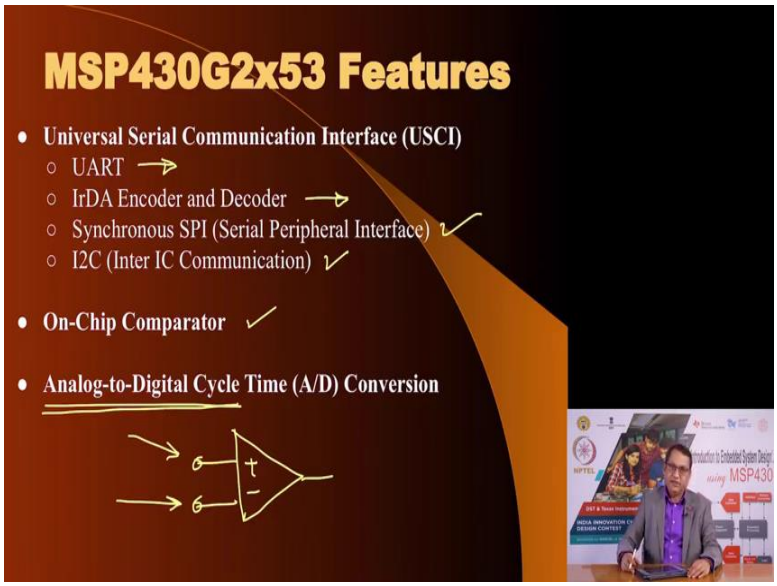

For serial communication, it offers a wide variety of communication protocols again, looking from the point of view of one of the building blocks, one of the six building blocks that we discussed, and there was this blog regarding communication channels. And so this microcontroller offers built in communication protocols and the communication interface is called universal serial communication interface. It has these options you can have a UYART, which is the universal asynchronous receiver and transmitter.

You could also utilize it for infrared communication, bidirectional infrared communication IRDA. It could be used for serial peripheral interface, what is called as SPI bus. And if you remember from those discussions SPI and I square C that is inter IC communication were classified as intra device communication that is within your gadget that you are building that embedded system that you are building. If you want the microcontroller to communicate with an external IC which had this or this protocol, you could use the built in protocol built in communication capability of MSP430 to communicate with devices on within the system.

It also has a on chip competitor that is an analogue competitor, meaning something like this. This and it is not just one single competitor, it has many, many inputs which could be routed to this or the pin so that you can do a variety of comparisons, voltages. It also has a ADC and we will see more detail about this ADC built in ADC.

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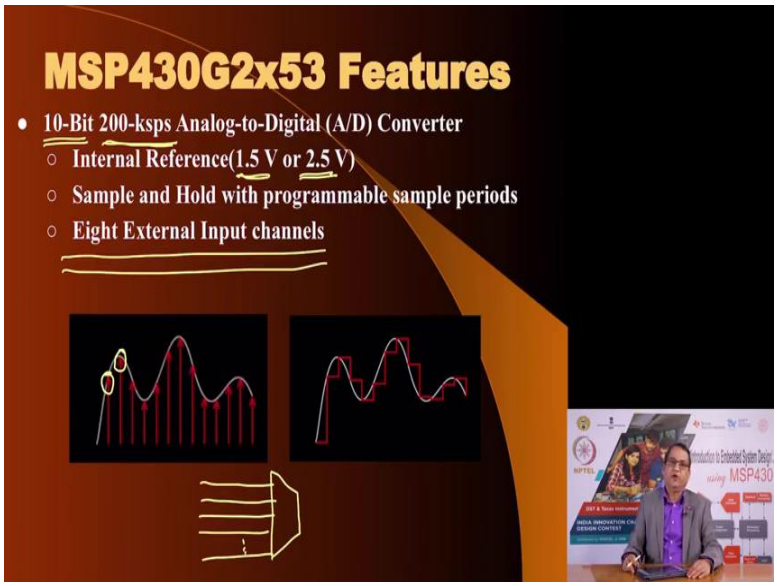

The ADC is capable of 10 bits of resolution here and up to two hundred thousand samples per second. That is the kind of maximum sampling rate that you can achieve out of this ADC.

ADC also require the reference voltage and you could choose an internal voltage reference of 1.5 or 2.5 volts. Of course, if you are if you are going to utilize an internal 2.5 volts of reference voltage then your supply voltage has to be obviously higher than 2.5 volts. You could also have an external reference voltage and we will see the pin out of this microcontroller, a sample microcontroller, see that there are certain pins on which you can connect external reference voltages.

Now, ADC is required that when the conversion is in progress, that the input voltage should not change. This is a critical requirement of a ADC and MSP430 has an integrated sample and hold units where the sampling frequency, which is up to 200 kilo samples per second. But you can sample it at lower frequencies also. And it has a sample and hold for all these inputs. And you can have up to 8, you can have up to 8 ADC inputs. That does not mean that it has 8 ADCs it simply means that it has one ADC if I draw the ADC block diagram like this, it has 8 channels.

And with the multiplexer using a multi analogue multiplexer and you can select at any given time, one of the inputs will be connected to the actual ADC and a conversion will be performed.

And this is how the conversion would look like if you could sample it here, but in reality that value will remain constant till the next conversion begins here and so on.

So, away from which the way form which is shown invite will, once you discretise it will be represented in the red signal that you see in this diagram, this is the result of discrimination performed through ADC.

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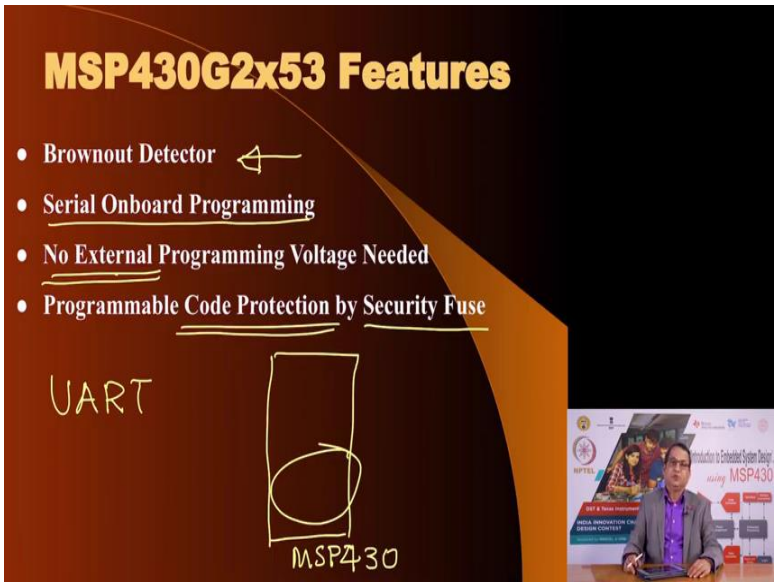

Now, we will discuss more features that MSP430 has and I encourage you to map these features with the salient features of modern microcontrollers that we had covered in a previous lecture.

And you can realize you would realize that MSP430 is a truly modern contemporary microcontroller. It has reset source, one of the ways of resetting I had mentioned is a brownout detector. Of course, it has use a reset. Also, we will see which pin is use for that you can program you can download the program into the memory of the microcontroller if this is your MSP430.

You can download the code in a variety of ways, one of the methods is called serial on board programming, which means it uses two pins to download program. Apart from that, you can use J tag interface for downloading the program and you can also use and in application programming method using a pre-programmed boot loader, which is available in the flash memory of the microcontroller, you could utilize it.

If you choose to use the in application programming that is programming with boot loader, then it uses the UYART which MSP430 has. And in fact our MSP430 evaluation kit, which is the MSP430 lunchbox, uses this method. This allows you to program microcontrollers with very little external support. And we will show you variety ways of actually making your own evaluation kit. In case you do not have access to the lunchbox, we will show you how you can create your own set up.

While programming in many microcontrollers, you require some external voltage. But in the case of MSP430, no such voltage required. And so all you do is just connect some wires to your microcontroller to your desktop or laptop, and you can quickly download the program. And once the program is downloaded in the memory of the microcontroller, you can secure it by invoking code protection, using security fuse. And this will ensure that the program, which is inside the microcontroller, is secure from being copied and hacked by external you know elements. So, this is a very important feature to protect the intellectual property of your product.

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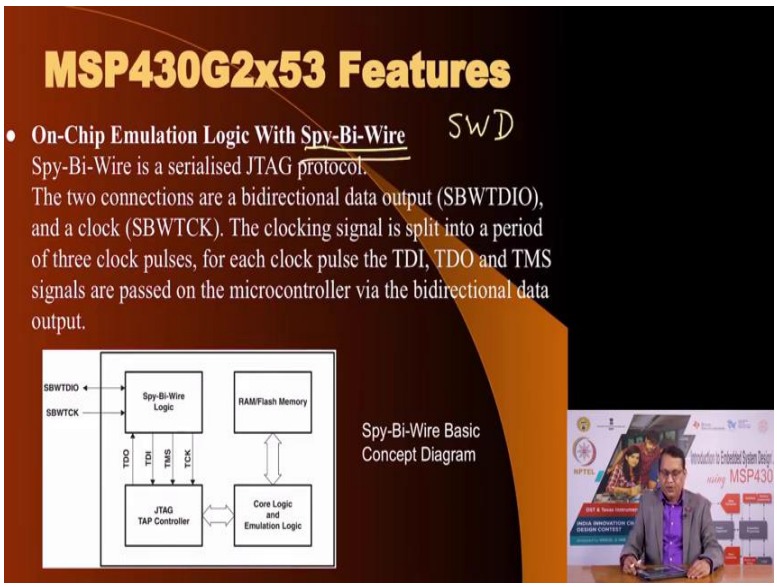

Let us see some more features it offers you on chip emulation, which means you can once your download your program, you would like to evaluate how it is functioning and it uses spy bi wire protocol, which is a SWD name that Texas Instrument gives to serial wire debugged, called spy bi wire, and it is actually a serialized J tag protocol.

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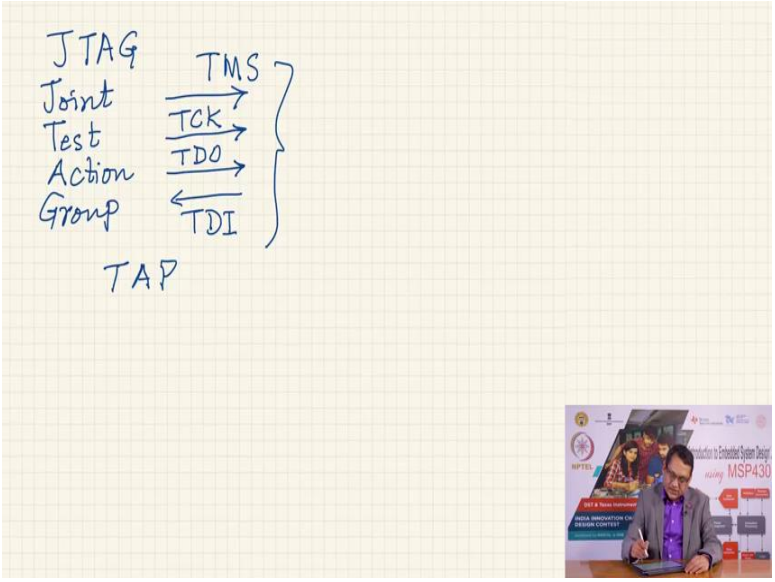

Let me explain to you J tag, because we have used this term several times a J tag is J tag interface it stands for Joint Test Action Group. It is the name of the protocol. It is a 4 wire serial protocol it has 4 pins TMS, a clock signal called TCK, a data output called TDO and a data input called TDI and this was primarily used by a manufacturers of digital ICs for testing, and it uses a concept called test access port over a period of time.

This protocol has been adopted and incorporated in microcontroller units and MSP430 has embraced it. And so you would see some of the pins of MSP430 have J tag functionality. But because it uses 4 pins for such microcontrollers where the number of available pins is less, Texas Instruments created a mechanism to use only two pins and out of those two pins to recreate the J tag interface of these 4 pins.

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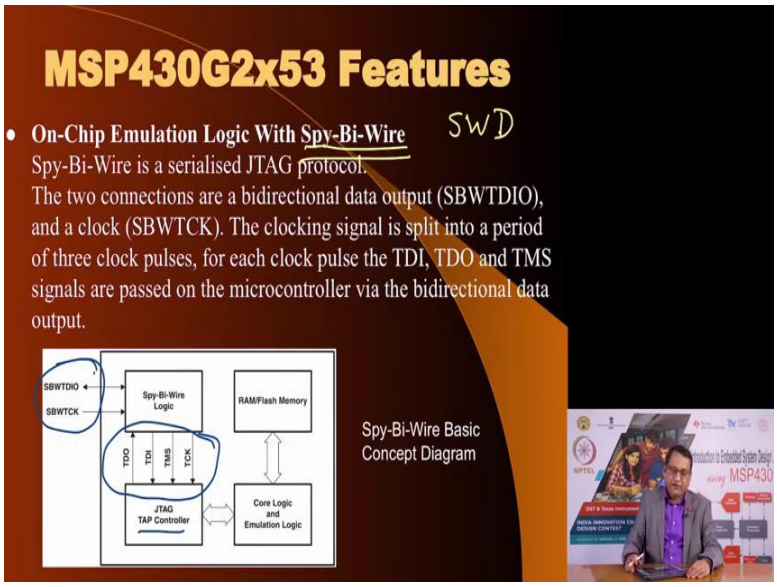

And that is the meaning of the spy bi wire protocol as you see, using two external pins here, it connects to the internal spy bi wire logic, and from there it recreates the standard J tag interface, which allows it to connect to the core logic and memory which is utilized when you want to debug your program, that after this instruction is executed, what is the result of that instruction? What is the content of a given register? You can access that through the spy bi wire interface.

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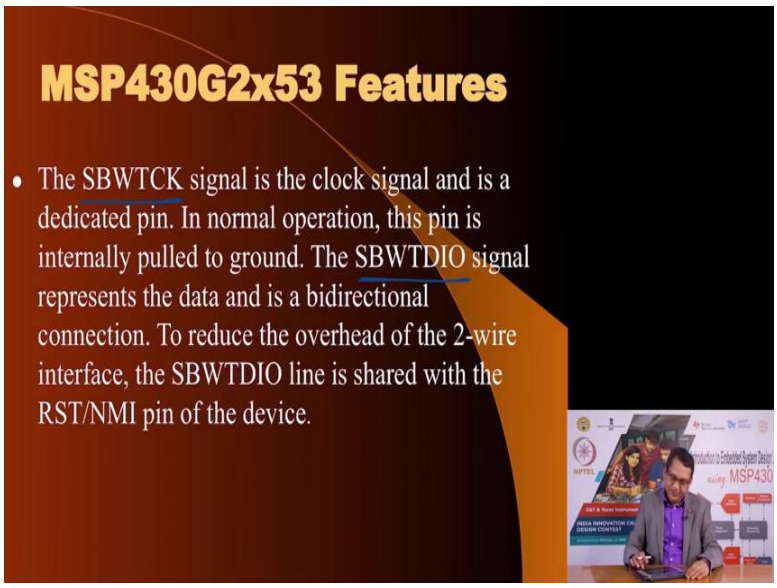

And this spy bi wire interface actually uses 2 pins, one of them is the reset pin and other is a pin called test and it has these pins are renamed SBW Clock and SBW data and using these to the internal J tag 4 wire 4 pins of J tag are created.

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This is the available options, packaging options, you can have MSP43 in bit form and we are going to use a DIP dual in line package IC for our experimentation board. You can also have it in SMD varieties of the type called TSOP. And then even small TSOP If you notice, it has pins on two sides just like you have on DIP. But when you have a quad flat pack there you get pins on all the four sides. So, this leads to even smaller size of package because then you are utilizing all the sides of the IC.

So, your MSP microcontroller, MSP430 microcontroller is available with so much variety. Let us go through the pin out or what we will do is we will consider the pin out in the next lecture because we are just run out of time for this session. I will see you soon. Thank you.