Design for Internet of Things

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Lecture - 02
Location, Applications and Power

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So, let us move on with this slide. This slide is essentially what I already showed you, what you see on the left side are three different types of RFID EPC Gen 2 tags. So, please remember this. The National Highway Authority of India, the tags that are applied there perhaps fall under EPC Gen 2, this is one type of tag, this is another type of tag, the third type of tag and then there is a fourth type of tag.

All these different types of tags are all part of the EPC Gen 2, EPC means Electronic Product Code Generation 2 type of tags. This is one technology which is part of RFID. Another technology which is part of RFID I mean it is confusing, because you say what is another technology in RFID? You can think of RFID like an umbrella, different type of technologies supported under this umbrella technology called RFID.

Another technology is the Near Field Communication. And what you see on the right side here is essentially this Near Field Communication. Now, what are the key differences in these things?

Well, I think that is important, we should know the key differences. So, let me explain to you those key differences. If you look at the EPC Gen 2, EPC generation 2 and if you look at NFC, both of them fall under the umbrella of I think this will be a better picture to draw, let me redraw that, I will say RFID, I will put one arrow like this.

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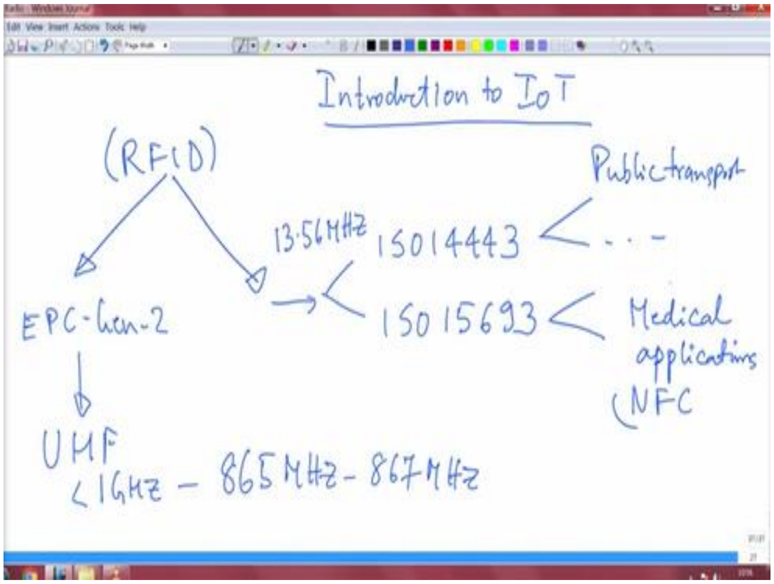

I will put this as EPC generation two and another arrow I will put like this and call it this is EPC. This is EPC dash. This is an NFC the key differences are although they form under the umbrella of RFID This uses ultra-high frequency this work in the UHF range which means this is the sub one Giga Hertz range. Typically, in India it is 865 let me write it a little bigger, it is 865 Mega Hertz to 867 Mega Hertz, this is the UHF range.

This one operates in 13.56 Mega Hertz, extremely close range and you can think about it like this that you can have a tag like this, I mean I am just showing you an EPC Gen 2 tag but never mind for an example. If this is an NFC enabled phone, if you want to read this tag you have to do it like this almost in 1,2 mm kind of spacing your to do because these runs. And how do you charge the NFC tag?

This is not through RF range, but this is inductive power transfer. The so you by induction you have a coil and through induction you charge that the NFC coil NFC sensor and then the NFC sensor will back scatter the data back on to the NFC phone enabled phone. So, that is essentially what happens in the in the world of NFC. This again leads you to one more competing you know range one more competing technology is related to the so, I must tell you that these two things are NFC is well known you will know that it is NFC but there is an ISO standard for them.

There are two NFC ISO so I will move this. You can say I will move this and show you that there are two ISO standards one is called ISO 14443 and the other is ISO 15693. These are the two types of standards, and you can have again there are differences between these two, ISO 15693 are those which you can use it for medical applications. And typically, this is what people normally call as NFC systems.

ISO 14443 is what you see in public transport systems. Several European countries and other places what you actually do is you carry like a credit card you have a credit card size the let us say a card whereas you enter the bus there is a box, that box essentially is the reader and this card need not be shown against that it can be inside your purse also. You have your purse, money purse inside that purse there is a pouch for putting your card, you take out your purse, show it against the reader, and then it enters the time when you entered the bus.

Before you exit again, you show it shows it will make a record of that and then we will tell you how long, how many stops you went and all that. So, it keeps again keeps track that is typical of ISO 14443 which are used in public systems. And there the range is slightly better because the card is inside of the purse it is in the pouch of the purse. So, that gives you a better range. But then it is also in 13.56, please note I think this is the key point 13.56.

The other application which we will spend time is with respect to medical applications and that is ISO 15693. So, both of them fall under 13.56 but you have to know the differences, you can have other applications by the way, I just gave you one possible application. So, what we are showing you here is this if you go back to this slide, if you look at this slide this antenna is either it is usually 15693 kind of antenna.

In any case, antenna is tuned for a given frequency the ISO 14443 or ISO 693 is more of a protocol, which is running behind. So, the antenna can be used for both 14443 as well as for15693 whereas what you see on the left side three of them? 1, 2 and 3 are all these antennas, for the UHF EPC generation 2 kind of tags.

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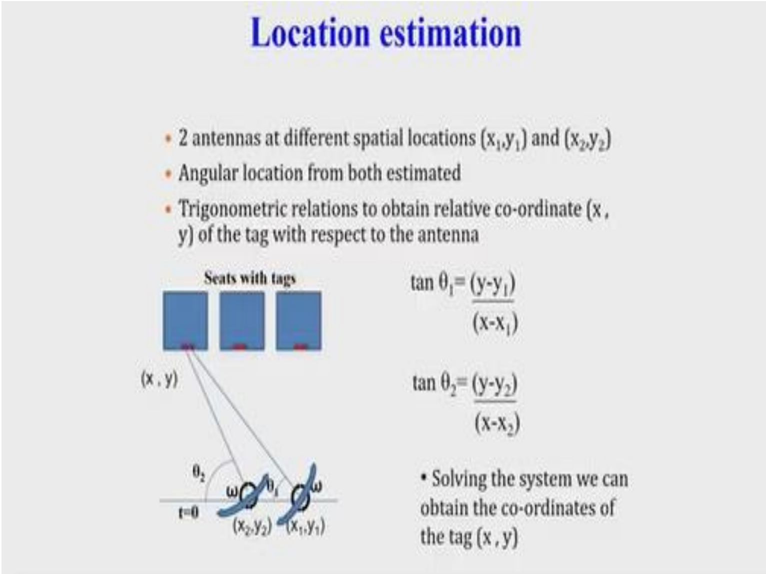

Now, I did mentioned to you about these RFID tags, let us put back this tag and let us put back this reader. Here is a tag and here is a reader. Supposing I also mentioned you that location is a very important problem, we did talk about that. And we said GPS is required and then you could do step counting and all that will come to that. But even here, the look at the problem with RFID, it can give you the code that is sitting here.

If you throw RF energy, it can give you the code, but it will not tell you where the reader will not know where this tag is nobody knows where the tag is. So, you need to do location estimation of tags. That is a problem in RFID world, and it can be a very challenging research problem. And our labs have looked at that in sufficient detail. So, you must know how do you do location estimation of these tags?

So, one simple idea is supposing I have this is a tag which is in a fixed location. And I have this reader, I read in one location, and then I move it by a finite distance, and I read it again. So, I have two distances D1 and have D2 from here to here, as well as from here to here. With these two distances, you can do some very simple calculations and that is essentially what I have captured here. Either you move this antenna to two positions, or you have a single reader with to antenna. That is also possible one next to the other.

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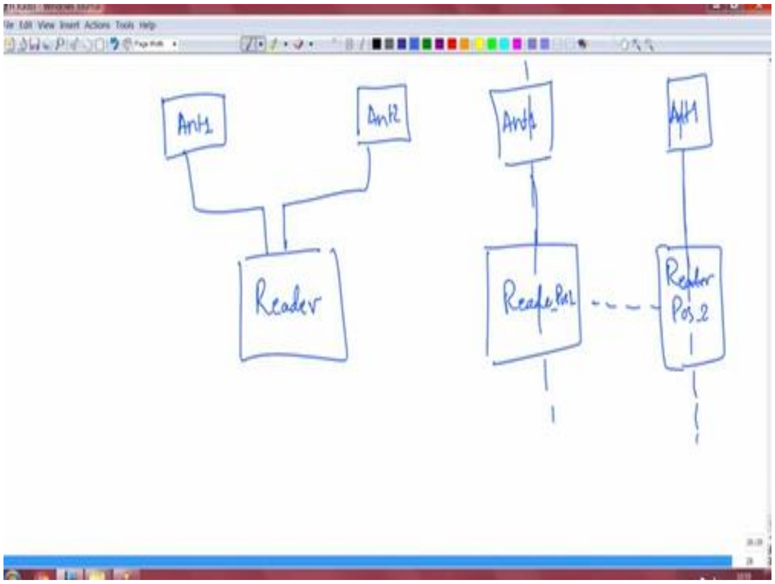

You can think of, let me draw a picture you can think of a reader to which you correct one antenna and another antenna. So, essentially you will have two ports for the antenna for the reader you will have two ports for the reader. So, this is reader is the piece of electronic, this is Ant 1 and this is Ant 2 and this is the same as supposing you have one reader you have the reader you have just one single antenna you have only Ant 1 but you know that you read it here then you move this reader to another location.

So, again you have reader to a reader position 1 reader pos 1 and this is reader pos 2, pos 2 means what? Position 2 again this is the same antenna Ant 1 this is reader position 2. So, if you know these if you move the reader to another position, it is easy to get you can simply solve the system we can get the you can get the coordinates solving the system we can get we can obtain the coordinates of the tag x y.

So, you are interested in so, let us look at this particular picture here. So, you have two antennas at two different spatial locations x1 and (x1, y1) and (x2, y2). This is nothing but antenna this is nothing but antenna meaning it is nothing but the reader because if you have a single antenna, it can be like ant reader moving from this position to this position or reader having antenna position here and another antenna position here.

So, your (x1, y1) and (x2, y2) and then you know this angle so, here is what you are you do not know you are interested in finding out the (x, y) location you can easily get y1 the tan theta 1 that you have here and this is a theta 1 and this is the theta 2 you do tan theta 1 you get this expression equation very simple equation and tan theta 2 you get this equation. Solving the system we can obtain the coordinates of tag (x, y) very simple.

So, this is I think you should try this very simple the expression for you to try. So, usually this is also called tan theta method for some reason. Anyway so, in fact, that is the reason is it uses tan theta. So, very simple way of localizing tags. Anything you want to know about localization of this nature, you must look at one algorithm which I cannot forget. It is called the music algorithm. Please look up music.

If you Google for music, you will find information on localization. So, this is with respect to reader. Now, what about the mobile phone part? See, this is another interesting thing. I said that if you move like this up, down, as you keep walking up and down, you will see that the Z axis is actually moving up and down plus you also have the Y axis moving forward and of course, very little movement along the X axis.

How does that signal look? Can I actually get a signature from it? The answer is yes. And look at this what I have done. Here is an IMU output that I have shown.

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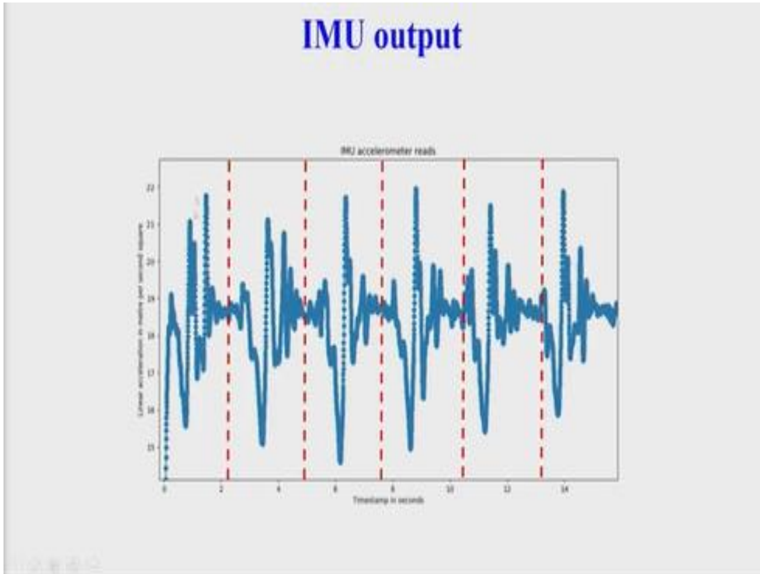

What I have shown you is on the x axis is time on the y axis is linear acceleration in meter per second square, acceleration is measured as meter per second squared. So, this is your y axis. Look at these peaks, this peak here I should show it with this, this peak, then this peak, this peak, this peak and this peak, and this, we can look at this line here. So, it is easy for you now to say this is first step, second step, third, fourth, fifth, sixth steps. So, six steps were taken by the human, every time the foot was put forward, you get a peak.

Then this is from the back, back foot this is the front foot, back, front, back, front, and so on. So, you see, it is so easy now if you know the starting location of the (x, y) location of the human and you know the steps that were taken, then you actually know the more or less know where the human is currently positioned without GPS there is a catch. What you do not know from this? It is the stride length that you do not know, you only know the step count, how much he covered, nobody knows. If it is a little kid, you will get the same waveform.

If it is a six-footer, you will get the same waveform, but six footers stride length will be different from a little kid. So, this is not you will have difficulty. But then you look at the waveform, analyze the waveform, maybe you will get further information, and there are out there literature out there on how to estimate the stride length from an accelerometer. So, this is very, very important you must know how to localize systems as well either it is RFID technology, or whether it is using mobile phone technology and so on.

Other types of sensors are possible, you can apply as many different types of sensors to understand the mapping and understanding the where the location is so many radar systems for instance, LIDAR systems, for instance. Look at them as devices which not only they give you a wealth of information, not only about the surrounding environment, but they can also be used for the purposes of localization, this is important thing.

So, let us move on. Then finally, we have to look at least one or two nice examples of IoT we have not even shown you and a good example of what an IoT is, I am not going to show you the regular stuff that you may find on the internet. If you say examples of IoT you will find, but I will show you some exciting stuff that we did in the lab. And let me point you to this little video. This video is done by our students in the lab.

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And what they are trying to do is, let me play it, you will see it for yourself. You see that the kids are putting students are putting things together and this is a surprise. And here is a hydrogen cylinder. And they are about to launch a hydrogen balloon. There so you can see they are inflating a hydrogen balloon; hydrogen has to be of extreme purity in order to give you a good lift and that is the payload that the student is attaching to it.

So, he is attaching about 1.5 kg's payload, they tie it up together. And they are about to launch the helium not hydrogen, I am sorry, this is not hydrogen, this is helium, helium balloon. Helium should be of extreme purity in order to get a good lift more than 99%. There you go, the helium balloon is going up. The balloon is using material called neoprene. So, these are neoprene balloons.

They can go up to a kilometer if not more, high up in the space, the payload is there. And here is what you see is the building and what you saw there are solar panels. So, what is the big takeaway? The takeaway is, you can use IoT devices, you can embed these, you can have a payload which has IoT sensors in order to calculate.

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Let us say in this case, the harvesting opportunity of the rooftop can be estimated using these things, you are interested in the green cover of your locality. Why not you try a helium balloon with required Sensors connected to it? In this case, we had applied camera sensors, as well as Wi-Fi communication devices, which were loaded, and then sent up so that as it goes up, it starts beaming pictures down, and you get an aerial survey of the whole thing.

And now this once it comes to the laptop or computer or wherever you can upload this data to the cloud. And in real time, people can either you can look at the streaming video or you can use this data to map in real time the harvesting opportunity available on the rooftop of a particular building. So, you can start collecting a lot of data from it. So, the point I am we were trying to say is that the IoT applications are not just limited to land, they can also be applied in space, they can also be applied in terrestrial systems.

And so, folks think about IoT out of the box, applications of IoT out of the box, so that you will generate newer and newer applications and for the betterment of human beings. IoT is all pervasive. Today, several devices and several appliances in our houses have all become IoT enabled, refrigerators are IoT enabled, fans are IoT enabled, light bulbs LED light bulbs are IoT enabled.

Why do you think they have to be done this way? If you take fan and if you IoT enable it, you will know that you can enable switch on, switch off, control speed with your mobile phone, not just by sitting inside your home, but you can enable it for elderly people sitting in your office, you press a button the fan will start. So, you do not need to be physically there to in order to enable all these appliances.

And in the evening, if you want to switch on the lights in your house, people use timers and then program those timers to ensure that lights come up automatically when people are not in the house and all that you can do. But you can also do it this way, you can see you can sit in the office and you can switch on the home light bulb by just sitting in the office I buy in the evening time, you may want to can so many things can happen.

You can also know the power consumption of these devices, how long you have kept it on how long you have kept it off. And you can actually learn from all the data that is getting uploaded and use that data to program to make things intelligent. After all, if you look at the devices that have come related to products like you know thermostats and so on, which have come out from a company called nest those devices are all basically learning devices.

They have just collected data learned from the data that was collected and understanding patterns of humans and then making things easy for humans. Let me tell you that today for very economical prices, you can buy these devices and start experimenting them at home. One such device which I saw on Amazon is right here.

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Look at this. This says you can buy an orient electric arrow slim 1200 mm smart premium ceiling fan with IoT remote and under light. You can buy this for about 9000 rupees. This is a device for the home you can control all these devices from wherever you are. This is one part and I have one more in my hand. What is this? This you think is a lamp. Yes, it is. It is an LED lamp, and it is IoT enabled. This is from Philips. And there is a product called leaf x or lifx as it is called.

I do not know whether I should hold it this way you can see it here. This is this way lifx looks at this product. This you just Google it you will understand what kind of IoT is an outstanding IoT product, there are many clones for this kind of product you have cheaper products. Now, I heard that you can buy an LED lamp now today for IoT enabled LED lamp for 600 rupees, 5 to 600 rupees.

So, things have invaded our daily life, and everything is centered around a mobile phone. These devices can be controlled data can be collected from these phones, you can learn from the data, put a model and learn from the data, come up with patterns and efficiently use these devices. You know when to switch on when to switch off. It can add other sensors around you ambient sensors and you can actually switch off these devices if you are not present.

You can have presence detector sensors, PIR sensors for instance can be put enable those PIR sensors. See if there are humans then keep the fan running, keep the light running. Otherwise, you PIR gives a signal and says hey I do not find any humans around me. The fan is switched off the light is switched off. This is one thing that you can do. And learning from patterns and enabling things for comfort is very important.

If the light comes to know that you always come to the house at 6 o'clock or 6: 30 at 7 o'clock in the evening and you do not want it to be dark, the lights can go on exactly at that time because they know that the owner of the house comes at that time. The owner, they also know what should be the fan speed for a particular for the toner. So, they may want to start operating the fan at a particular fan speed.

So, it can give you a lot of comfort, but you need to have a technology behind and that is where IoT actually plays a very important role. So, what is the summary? There is just no point today to make devices isolated, you have to connect devices to the cloud, you have to connect devices to the out, you should connect they should be internet enabled, you should collect that data, you should analyze this data and you should come up with patterns, you should make these devices intelligent.

That is when you actually say that it is a full blown IoT solution. Now, just to give you an overview of a IoT node and corresponding its power consumption. It is a very complex topic though. And there are many aspects, many facets of this particular aspect of power consumption in a node has to be looked up.

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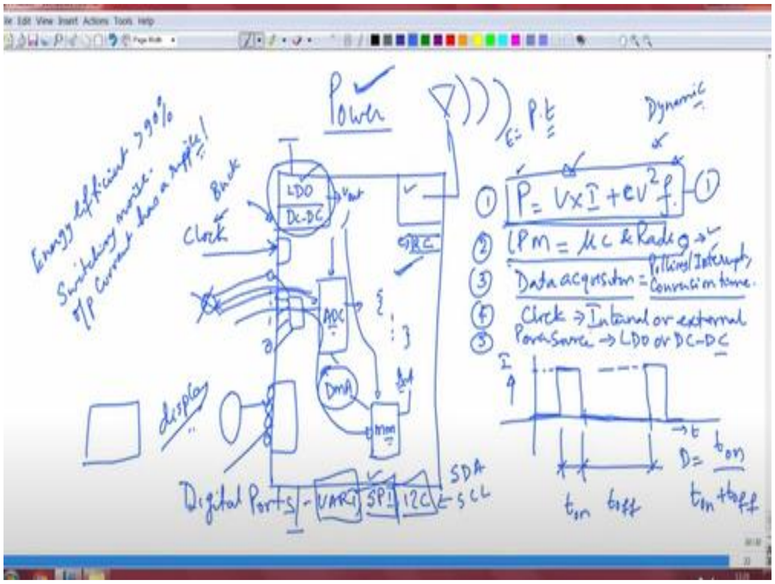

Let me point you to a picture which I drew, it is not a complete picture, but it will at least tell you some interesting things about where all and how all you should control and look out for knobs which allow you to keep the node in terms of its long lifetime right extended lifetime. We said nodes have to live for 10 plus years and they are can be battery driven or they can be energy harvested.

So, how do you ensure what are all the places' hooks and levers that are available to you to ensure that your system is not performing well under the required budget energy budgets. Here is a picture if you take a typical microcontroller SoC, you will have this section on the left side which is called LDO dash divided by DC-DC. So, I cannot divided it is either this or that. You supply power to a controller; it may supply the output power, output voltage either using DC-DC or low dropout regulator.

Typically, these are buck converters these are switching buck converters when I say DC-DC I mean here buck converters. Now, this Vout that comes from here is actually used for powering all the different blocks, all these blocks are powered using this Vout. Now, we know that any switching regulator or any switching system is highly energy efficient. If you want high energy efficiency greater than 90% or so.

You obviously have to choose a switching regulator and to that extent, the DC-DC converter is definitely a good choice for lowering the power, lowering the power consumption of the SoC. But then DC-DC converters, while they do that, they also introduce switching noise, the output current has a ripple. Now, if the ripple is high, then any sensor that is connected to this to the ADC port under the presence of this ripple you will not be able to detect an extremely low signal that is coming.

Typically, if you are looking at medical sensors, medical applications sensors, ECG probes, EEG electrodes and so on. Those have very small voltages coming out the sensor values are very-very small, which requires a preamplifier in fact there you have to amplify and then transmitted. That itself can be a problem if you are powering through a output which is based on a ripple-based output coming from a DC-DC converter.

So, your choice of whether it should be a switching regulator or a linear dropout regulator which an LDO, will largely depend on the kind of sensors that you are going to connect here. If they are purely digital sensors which are connected to these digital ports, then you will not have much issue with respect to the choice of switching regulators which are embedded inside the SoC module.

So, this is the first point. So, you have to look at how should I use this, or should I use that so that you will be able to look at it from the power perspective. Now, this SoC itself has two parts, one is the controller, the other is the radio. The SoC itself will support controller itself will support multiple low power modes and you are to look at their low power modes and use them configure them appropriately any data sheet with respect to the controller of interest, which has an embedded radio will support low power modes.

So, please look up the low power modes of the low of the microcontroller as well as the radio. The next point is this is an equation which I am sure you might have seen many times. This is the static power consumption of the controller of the SoC and this is the dynamic power associated with the SoC. If you put the system to very low power, then the power can the current consumption is minimal.

This is the minimal current consumption point, that means the power consumption due to static also comes down and if you are operating it at a low frequency the crystal clock frequency is low again, then the power consumption is low. That is with respect to dynamic power consumption. Power consumption continues to be low even if you have an operating voltage which is significantly low.

If you have two-volt, or let us say three volts, if you take a three-volt VCC, 3 squared is 9. Whereas if you take four-volt, you have four squared, that is 16. So, you can see that the power consumption by just a one-volt change operating voltage change of one volt blows up the power like anything. So, you have to be watchful of the fact that your operating voltage also has a bearing on the dynamic power consumption.

This is the switching capacitance; it will also have an impact and it is usually mentioned the C is switching capacitance. If you are operating at lower frequency, it will have lower power consumption. But the time to execute will also increase because you are not operating at high speed. So, there are tradeoffs of operating at a low frequency as well as the time it requires to compute something, some value.

So, this is point number 1. Point number 2, I mentioned is all about the low power modes. Point number 3, is about data acquisition. For many times you ignore this, that is the problem and I want to point out a very important thing here. When you write your ADC driver for acquisition of data, whether you should send a command to the sensor. Whether sensor is here? It is connected to one of the I will show it slightly bigger, so that or I should show this smaller.

This is a smaller port this is also a very small one and I will show a sensor which is slightly larger, this is your sensor. If you write your code such that you are asking the sensor you are asking you are configuring the ADC to obtain the data, you waiting for the system to respond back with its data via the ADC it comes back to this code here. So, it is writing in RAM, this can be horrible if something goes wrong with this sensor node.

If the sensor fails or malfunctions you are eternally waiting which means the CPU is in on state and you are burning away a significant amount of power which is going back to the equation one. It is now on for a longer time because energy is to be calculated power times the time. So, your energy burning starts increasing and this you to keep a note. So, how do you write your driver?

Such that he just you give a command and wait for the sensor to respond back and take the data whenever the sensor response rather than you waiting for the data to come back. You proceed with other activities and only once the data comes back, you start processing the data which means polling or interrupt. Which one should you choose? Polling is simple, very simple, you can do. But if something goes wrong, you are in trouble.

The energy consumption can go up drastically, interrupt is good, but interrupt is hard to configure interrupt handlers have to be written and it is a little more work, it is not hard, it is in a way, it is a little more work for you to do. Also, ADC requires a clock ADC requires a clock to convert the analog data to digital data. If you do not choose the clock frequency appropriately, the conversion time will increase from analog to digital the conversion time will increase lower clocks will increase the conversion time.

If the conversion time increases the processor is ON for a longer time, which means again the power consumption goes up here. So, this this power this term will continue to start blowing up because in terms of time, this is another thing. Then the controller itself you can choose between internal oscillator and or external oscillator. Now if you choose an internal oscillator, you typically come with an RC oscillator which is built into the system you do not need to connect anything externally.

So, let me show this as another block. So, you will have a RC oscillator as part of the block here I should make it touch this. So, that you know it is part of the silicon itself the RC oscillator is there. But RC oscillator is unstable and for temperature variations it can change and can drift. So, you have problems of drift, and it is ability to scale up to higher frequencies is limited. So, RC oscillators you choose when your frequencies are low operating frequency or low clock frequency requirements choose RC oscillator because it is energy efficient.

And it is at but at the same time it has other issues that it can have a drift and so on. Whereas you can also use a crystal oscillator by supplying an external crystal. You need an external crystal means number of components go up cost might go up, but you will not have drift problem. The clock is stable, and it has the ability to you know work over a range of frequencies. So, that is good thing about the application of external clock.

Of course, it has issues of no higher power consumption and so on. So, again, make a note whether you want to choose internal RC oscillator or whether you want to choose the internal oscillator, or the external clock again has a bearing on this power. Then in general, if you have digital ports, you may want to transfer data using either a UART port or SPI port or I2C port, each one of them have their own advantages.

If you choose I2C typically these are open collector outputs, and they need some sort of additional circuitry in terms of pull up resistors and so on and the advantages you will get only two pins. Typically, they are called SDA and SCL. Whereas SPI can be either three wire or four wire interfaces but gives you much higher speed compared to UART. So, whether you want to choose a UART or whether you want to choose SPI, I2C again has a bearing on the power.

Now if you take UART it says slow device, you have a device that is connected to a load that is connected, let us say a display system. And this display is connected over UART, and you are waiting for it to get the data so that it can display something on the screen. Maybe it is not a good idea to choose UART because data rate transfer the lot of data to go on to a display system and you have to transfer it quickly.

To do that UART is not a good idea, because again power consumption will increase because your transfer rates are limited. Maybe you should go in for SPI so that you will be able to finish the transfer quickly. I did not discuss this DMA. I will come to the DMA in a little detail. But at this stage it is also important for you to note that acquisition of data from the ADC and righting to memory that sends value need not bring the CPU to active state.

It can continue to remain in a sleep state because DMA is configured to get the data like this onto the memory and then issue an interrupt, then it can issue an interrupt to the CPU. So, these techniques essentially will give you ultra-low power operation. This is just broadly telling you the possibilities, the levers, and hooks that you have to choose to improve the energy efficiency of your embedded IoT node.

So, that is all I have this last picture is telling you about the duty cycle, anytime you put the system to sleep, it goes to off state, this on state is that time and it consumes some current. So, this is I and this is time on the x axis here, this is time. So, you can see the duty cycle typically is Ton by the simple expression Ton by Ton plus Toff. So, you keep your on time low that means you can ensure that nodes can sleep for extended period of time.

So, folks this is an overview of the power we have to go into each one of the details and understand them drill down to some amount of detailing before we know how to configure system for 10 plus years of lifetime. How to characterize the CPU? Which CPU to choose? Why did we choose this we did not write anything about this CPU here? What is the parameter and all that? As we go along, we will try to understand. Thank you very much.