Design for Internet of Things
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Lecture - 17
Battery less power supply and battery life calculation for embedded devices I

So, ultimately whether you want to you drive your embedded system the system that you have plan to build now the system that you have to build, either with a battery or with harvested energy you must know what should be the size of the battery if it is a battery driven system, or you should know the size of the output capacitor if it is a super capacitor what should be the size of the super capacitor that you have to ultimately used for storage of energy right. Even before you do that, you should budget the total power consumption of your system properly. How much is the system microcontroller taking in its sleep, how much is it taking when it is active, how long is it going to remain in active condition and so on and so forth right.

So, this you should understand and you should be able to do quick calculation before you decide anything with respect to the kind of powering energy storage device that you have in mind. Let us take battery as an example that is a easiest right.

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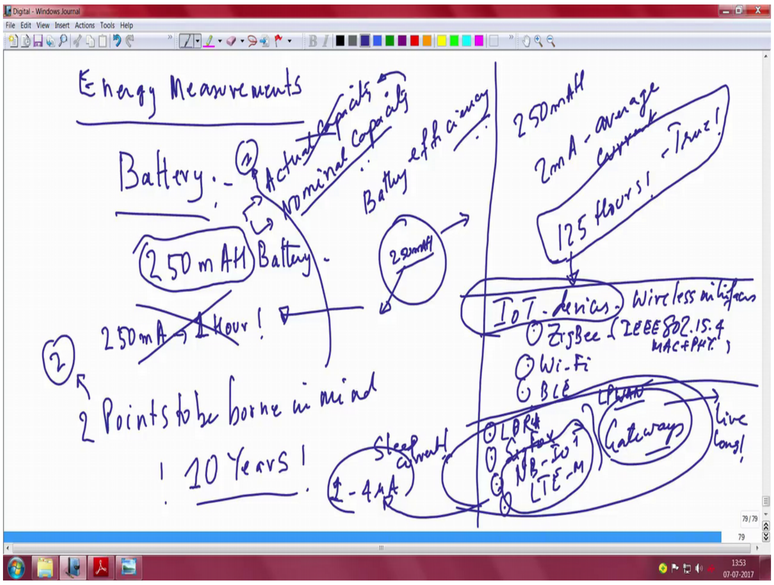

We all are able to connect to a battery as an example, first let us go to some real high school stuff which perhaps most of you may not even sometimes be aware that there are some things which I (Refer Time: 01:44) mix that you should be able to you know be very clear about. Take the case of a 250 milliampere hour battery, you have a 250 milliampere hour battery in question what does this mean? This means if you draw 250 milliamperes it should last for 1 hour right that is what you would think. If you draw 250 milliamps it should last for one hour the answer is no that is incorrect. This is incorrect it never works like that it is definitely less than an hour and so, do not go by the fact that it is something is stamped on the battery. First thing is this is not the actual capacity first of all this is not the actual capacity; this is not the actual capacity.

This is what you known as the nominal capacity. So, what manufacturer will tell is he will give you the stamping on the battery actually is an is basically a nominal capacity. The actual capacity should be calculated from the nominal capacity and that is where battery efficiency comes into picture this is one part. So, if you look up a battery and you see that there is a 200 milliampere hour battery, first thing is do not look at it from the fact that it is the actual capacity, look at it as though it is the it is actually the nominal capacity mentioned by the manufacturer. Second thing so, there are two things I said right one is this part the other part is this thing, do not ever assume that if it is a 250 milliampere hour battery that you will get it for one hour.

Both these points two points to be borne in mind, to be borne in mind and which are the two points? This is the two points point number one is here and point number two is here these are two separate things, but these are very useful for you before you actually find out what is the size of the battery that you want to use for your application. In reality it means this. So, what is it mean? This number cannot be a number just given out for fun by the manufacturer right it simply means if you have a 250 milliampere hour battery, it simply means if you draw 2 milliamperes continuous current or I would say average current, I will be a bit more careful average current if you draw 2 milliamperes of average current, the battery will last for 125 hours, this is true this is true in a way ok.

Of course be careful that if you apply the second point this is let us say the first point is with respect to the fact that you are just looking at the nominal capacity and then you are arriving at this part. The other party if you apply it is obviously, going to be even lower right because we have not yet added the battery efficiency to make this calculation based on the actual capacity. So, therefore you see you are far away from just buying a battery and just putting that battery into your load system you should never do that. This is the first point that you have to you know sort of keep in mind. Another important point is most of the IoT devices IoT devices, use wireless interfaces I did mention to you about the different types of interfaces that are available for these devices, you have for this communication device technologies, you have zigbee which is also called the 802 dot 15.4 MAC and 5 MAC and 5.

Actually uses MAC layer and physical layer uses the standard defined by the I triple e it is also called the 15.4, then you an have other technology such as a Wi Fi right then you can have BLE and so on Bluetooth low energy and so on and so forth you can have several different type.

These are all mostly from the access pa perspective, but if you are looking at wide area low power we did talk about the wide area low power which has Lora Lora wan protocol l p wan as their called low power wide area network protocols which are a technologies which are Lora you have Sigfox then you have NB-IoT you right you also have LTE-M p mention this, but I will just to recap that these are all possibilities for the l p wan for beyond the access devices, but more the gateway these are all for gateways right gateways right why I am saying all this? I am saying this because you may have to consider how do you want to drive these gateway devices, and how do you propose to drive these little access devices small little devices which have sensors.

So, it has an impact most often the gateway devices I do not think you will be able to drive with small coin cell batteries and so on. It is not going to work you must need either very large batteries or you should end up with connecting it to the grid supply right. So, these are the two things. So, all this energy measurement and all these discussions that you have to do is general though although it is very general.

I would say that you are requirement which I mentioned right in the beginning any design that you do any system that you design a put in place on IoT device for sensing monitoring actuation whatever has to leave for 10 years 10 years if you do not design your systems for 10 years, I do not think it is worth even trying for in an IoT application; however, gateway; obviously, you may have to be very careful, it will also have to ensure that this will have to live long as well live long and it should not be a power guzzling part.

Some of the nice things that stand that things have standardized is, whatever IoT device that you are using for sensing let us say the sleep currents are of the order of let us say a few microamperes, I would say 1 to 4 microamperes of sleep currents of sleep current right that seems to be also true for these l p wan systems particularly the NB-Io T and LTE-M actually propose that if you are not transmitting, they will be consuming gateways will be consuming something of the order of the communication link part at least we will be consuming currents of the order of one to four microamperes, which is very very attractive.

And which we will actually tell you that they then why should I not drive gateways also with batteries when it is possible, but given that gateway systems have to perhaps have multiple wireless interfaces one is to get data from several sensors which are placed in the field or several sensors from which it is aggregating the data and then using the wireless outgoing link essentially the wide area outgoing link which is essentially what we are talking about is it if not used we will be consuming one to four microampere.

Means clearly that gateway devices have to sort of work on either very large batteries or it should be there should be grid power. So, that is the real takeaway. Now this is one part, now what we will do.

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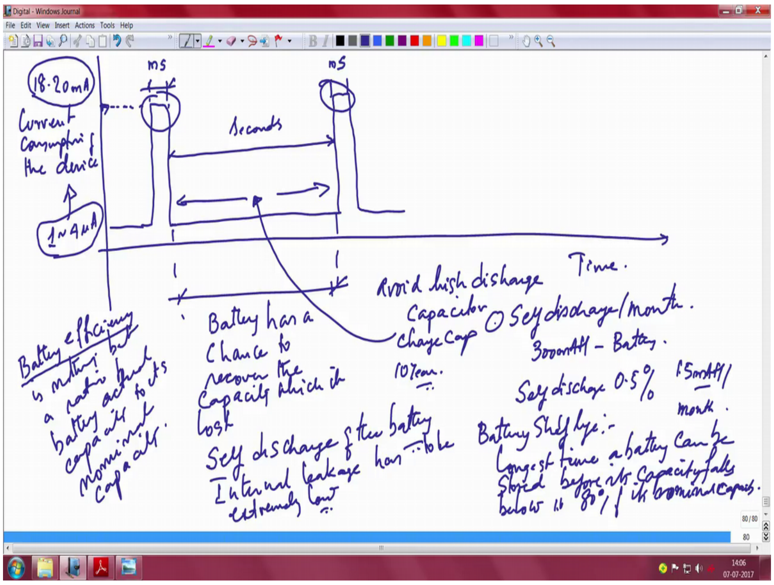

I will draw a picture and then I will try and explain a picture and I will also show you a measurement that I did in the lab. First let us understand one picture I will draw the x axis the y axis and I will draw the x axis. The x axis is time the y axis is instantaneous current consumption current consumption of the device, this is the current consumption of the device. I will draw something like this ideal like this and I will do this and I will do this ok.

Obviously I need to extend this like this little more just for completeness and put back time. Now this is let us say 1 to 4 microamperes because it will depend really on the kind of hardware that you are actually designing and of course, this we will have to be drawn bigger. And let us say this is 18 to 20 milliamperes just as a number. If you want to fix it to one you are free to do. So, if you want to fix it to 4 you are free to do. So, similarly here I just put this range because your hardware may essentially be somewhere in this range.

now so, this is this is time right. So, this one is some milliseconds a few tens of milliseconds this is milliseconds please note right. If this is milliseconds it is easy for you to say that this is indeed seconds'. This is seconds and this one again is; obviously, going to be in milliseconds. The something nice about this picture from a battery perspective one thing is this is the time over which battery has a chance to recover has a chance to recover the capacity. It has a chance to recover the capacity which it lost during this period which it lost I would say these are periods where it losts these are the periods over which it last it has a chance to recover the capacity, see that is a nice thing. Remember I mentioned to you about two terms with respect to capacity one I said is the nominal capacity stamped by the manufacturer, and the actual capacity which essentially is the term which you have to consider because of efficiency of the battery, battery efficiency is an issue so, you have to consider that. And battery manufacturers we will give you the actual battery capacity that is there is no problem.

So, essentially if you say if you ask what is this one, it basically it is the ratio of the batteries actual capacity to its normal capacity is this nothing but battery efficiencies nothing but a ratio battery efficiency is nothing but a ratio of batteries actual capacity and sorry battery actual capacity to its nominal capacity right. So, this is what the definition.

So, I am just defined it in a simple way. See if you do not want this battery to have high current discharge periods, you do not want this spiky nature of drawing a significantly high amount of current the high discharge current, discharge periods because battery is discharging quite rapidly when it is sourcing this kind of high current right. If you want to avoid high discharge and yet deliver the required current to the load, what you can think of us you can think of putting a capacitor at the output of the battery and therefore, when the battery and you keep charging this capacitor during this sleep period.

Discharge the capacitor in this period charge cap when in this period. This period you charge the cap and moment it gets on now the cap is actually giving you the required its giving you the required energy delivering the required power to the load in stuff drawing a directly from the battery right. So, it is like a buffer it helps you to ensure that battery life improves, because you will not get into deep rather high discharge not deep I would say high discharge periods, this is another thing this is one part of the story nicely done everything we understand, but do not forget there is something called a self-discharge also self-discharge of the battery. Now you are too battle this also if you say 10 year lifetime you will unless the self-discharge to the battery is extremely low you cannot meet this 10 year lifetime it is not going to work that way.

So, internal leakage is something that you have to avoid; internal leakage has to be as it cannot be avoided you have to buy a battery which has the least internal leakage has to be extremely low alright extremely low. So, please look up for all the specifications when you buy your battery when you select your battery it is not remember design for IoT is a lot it actually means I mentioned right in the beginning, design means choices. You will have so many in front of you, have to pick the right one these are all points that you have to pick up you have to keep noting. So, that you actually know which one you are trying to buy right which battery to buy if you take. So, basically what will happen is, the manufacturer we will tell you the self-discharge I am sorry discharge sorry self-discharge per month it will tell you, this who will tell you this will come from the manufacturer ok.

If you have let us say a 300 milliampere I will (Refer Time: 20:22) I like examples milliampere hour battery, if you have a battery this is the battery if you have a 300 milliampere hour battery which has a self-discharge which is about a 0.5 percent this is this one means you are looking at 1.5 milliamp hour right of its capacity is going down every month 1.5 milliampere hour worth energy is going down. The battery shelf life is defined basically as the longest time. Now, you can talk about the battery shelf life battery shelf life, you can be talking about this as the longest time this is nothing but the longest time a battery can be stored longest time the battery can be stored before its capacity falls below it is below how much 80 percent; below 80 percent of its nominal value or cap capacity that is the point.

In other words this is about whenever it goes below falls below 80 percent of its nominal a nominal capacity, you will say that that is the that is all that you can that is the shelf life of the battery. So, that is the other thing. So, keep this in mind this picture in mind and let us put down a few things. Let us say I will put down a table in this case and let us go about trying to see how we can build the story of this little table. So, for that what I will do, I will recreate this table and then we will rebuild the story.

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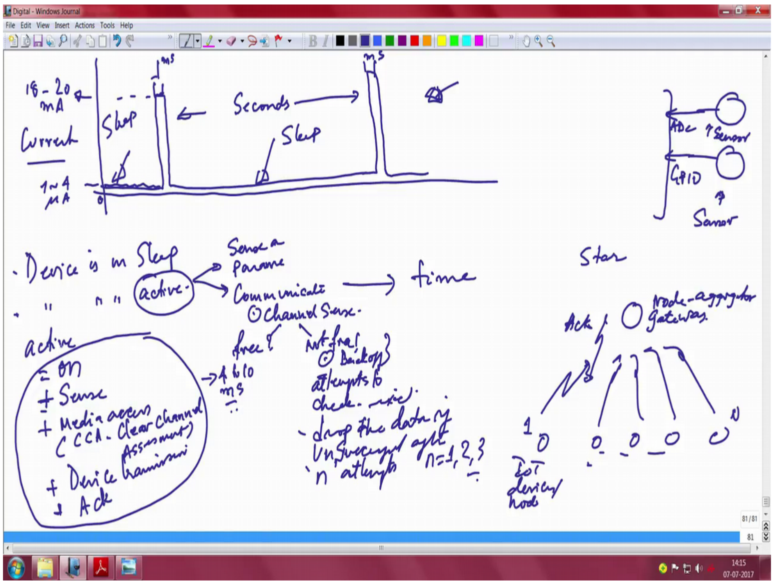

So, let me put this into the next sheet into another sheet, again I will draw this picture right this is 1 2 4 microamperes, this is 18 to 20 milliamperes,this is in hundreds of seconds and this is obviously, in milliseconds if you want to really depict it carefully you can actually right like this also. Make it very narrow hoops let me draw it neatly very narrow right.

Now, it becomes sort of compatible this is all in milliseconds and this also in milliseconds right this is also in milliseconds, and this is in seconds, hundreds of seconds this is time, this is instantaneous current. So, let us see what is the first step we let us put down several systems, several things that is by just looking at this picture, what is happening take a device. This device actually it is not depicting correctly. So, what I will do is you should show like this only then this is 0, this is that 1 to 4 micro amps, then this one can be shown here it still not perfect to scale, but at least I hope it will give you a feel that you are very close to 0 in this case. To begin with let us say the device is sleeping device is in sleep then that is this period right .then device transformers to active mode.

So, then there is active. So, device is in active mode it goes to active mode, what does it do when it is active? It could go sense a parameter how does it sense a parameter ? Either it can connect on GPIO or it can connect on it is ADC a sensor is connected depending on whether it is a analogue sensor or a digital sensor these are the two sensors sensor sensor right this is acquiring and if it is ready it is also trying to do a sensor parameter and then it is also trying to communicate how does it do this communication? It has to check for the medium see if there is any if there are other nodes in the network. So, each one of them are trying to communicate this is a star right this is a star topology, this is the node which is the aggregator it is could be a gateway, it is more powerful and these are IoT devices or loads which are out there.

So, one of them one here up to some n there all communicating. So, if this picture that you see here is applicable to this node it senses and it has to communicate to this gateway, but has to ensure that no other node is actually transmitting, that is how channel access it has to ensure that the channel is free. So, it has to do channel access channel sense to see if the system is free, the medium is free and then it does a transmission. If the medium is not free, free not free right if it is not free it has to do a backup of in other words it has to sleep and come back and then sense if it is free.

So, that is going to consume a little bit of energy right it senses and then goes finds that the freedom is not free goes to sleep comes back and re attempts. How many times is it going to reattempt that you can fix the number of attempts to try the medium is free, to a attempts to check I would say not try attempts to check that can be fixed to check can be fixed. So, essentially it will check how many times the node is the medium free and after that it can even drop the packet drop the sensed value drop the unsuccessful drop the data, if unsuccessful after some n attempts, n can be fixed to 1 2 or 3 something like that.

So, you can actually calculate how much time it spends and therefore, from there you can I calculate the energy it is require. But if it is free it can do a quick communication and be done right and how long is it going to do if it is free and it is able to communicate, it may not perhaps even take more more than 4 to 10 milliseconds it may not take more than 4 to 10 milliamp mi milliseconds then. So, you can actually divide this active itself into sensing the parameter and then. So, you can put sense communicate. So, you can say active is equal to you can say device is on.

Basically then, so you should not say put plus I will put devices on plus sense, plus medium check, media access I will say media access energy for that then essentially in the zigbee parlance this is also called CCA clear channel assessment, this is also called media access media access where it has to check if the medium is free, then does a device transmission right and then it has to wait for a ack back in this direction, this is the Ack right acknowledgement and then finally, after all this is done it has to go back to sleep.

So, you see you started with sleep you went into active mode you did so, many things in the active mode this many things and then you went back to sleep and again the whole thing started all over again. Let us put down some numbers so, that you will be able to connect alright so, far that I will do for device in sleep device in sleep.

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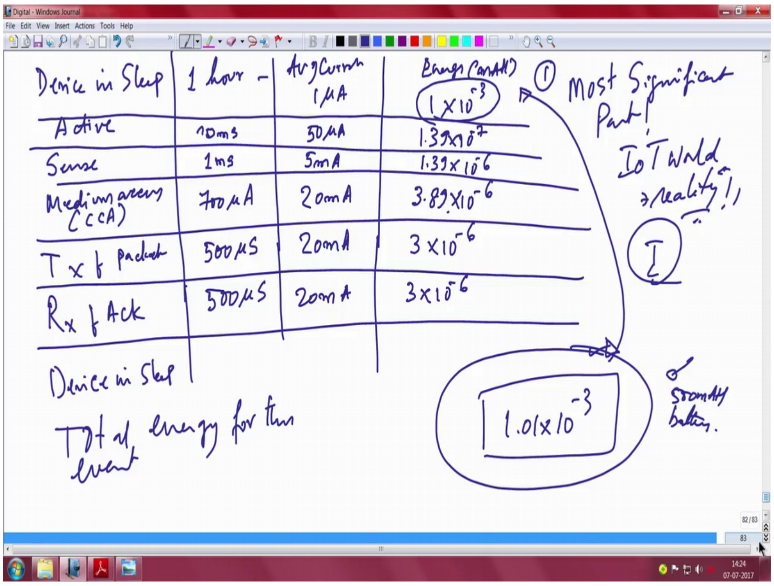

Let us say it sleeps for one hour. So, that is 3600 seconds. Let us say one hour and the average current consumption I said is anywhere between 1 and 4. So, I will take one to be on the lower side I always want the average current consumptions to be low, and that is the goal anyway average current is one microampere and energy. Therefore, in milliampere hour look I am putting everything in, ampere hour because batteries are available as ampere hour.

So, I have 1into 10 power minus 3 very good, so easy right. So, this is one column then this is the activity and device in sleep like that you can put active. You can put then you can also put sense right then you can put media access also known as CCA clear channel assessment then you put Tx of packet data packet then you also put Rxf ack acknowledgement right then you go back to device in back to sleep. So, it has to you are a fill up all this hoops. So, let us do this active sense access medium access transmit you see and so, on start putting some numbers here it is on active time for 10 milliseconds, but when it is on its not doing anything. So, you may want to not consume much this is only a very small number right 1.39 times 10 power minus 7.

But if you do sense it is not going to be simple you will sense for perhaps for one millisecond and you will consume some current for sure right that is easy 50 microampere 5 milliampere medium access this is for a very short duration this will be I am just putting some numbers 18 to 20. So, I will put 20, it is going to try right. So, it is going to try to try means it will switch on the radio and moment the radio is on it starts consuming sufficient amount of significant amount of current, then transmission is very very short right it is not even one millisecond. So, let us say half a millisecond.

So, I will say 500 or around 500 microseconds and this is also the same current this is 3 times minus 6 milliampere hour then it will have to wait for an ack for sometime and let us say it waits for also the same time and you can actually put the same time let us say just to be make it very simple and I will put back the same one that is appear. All of this this of course, it goes back to sleep. And so therefore, now you need the total energy for this one event that you found is one times one into something like this ampere hour milliampere hour what is interesting here the interesting thing here this this 1 into 10 per minus 3 milliampere hour that you see here is used during sleep right you see this this one and this one just look at this right.

So, something very very striking in fact, quite a revealing thing ultimately leading to the fact that device in sleep compared to all that is happening with respect to the other activities is the most significant part. Time and again time and again I found that this is what will happen in the IoT world this is a reality, but. So, this is one part this is one part of the story its story is not complete yet, this is I will say first part of the story let us put down the second part because we define so many things subsequent to this also right.

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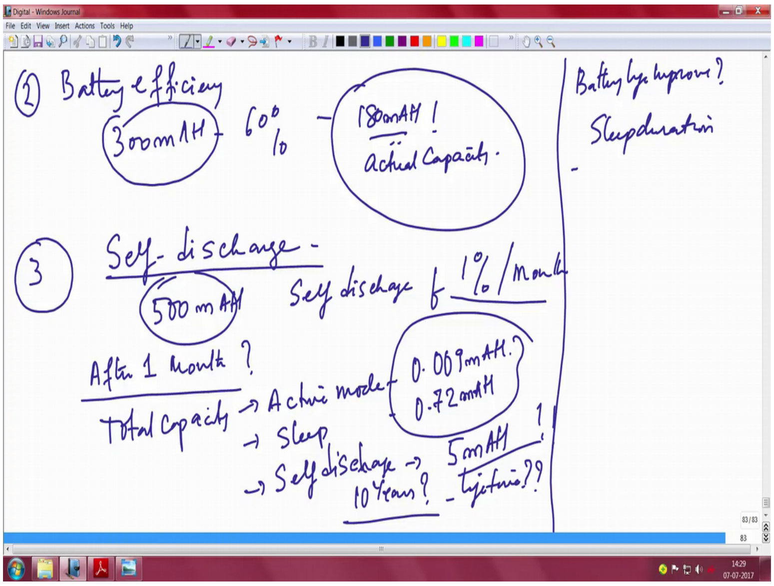

Second part is battery efficiency; again we are to go back and find out battery efficiency right we also did a definition of the battery efficiency in all that. If you take a 300 milliampere hour battery 6 percent efficiency means it is actually 180 milliampere hour battery that is the reality right.

So, is this nothing but the actual capacity; use this as with this budgeting that you got do not use 300 milliampere hour use this use this number well can you this is still the second step no there is another step, do not forget the important third step and what is that self-third step self-discharge we already spoke about that right. Particularly when you are talking about this low duty cycle you have to node this self-discharge becomes very very critical. Take another example if you have a 500 milliampere hour battery with a self-discharge I keep taking examples which are varying. So, that you get idea of 1 percent per month this is the self-discharge of the battery and if you apply this table apply this table on a I am applying this on a 500 milliampere hour battery I am applying this on that ok.

After one month what will happen after one month after one month what happens after one month after one month the total capacity used by the device during the active mode and sleep mode is at that total capacity will be for active mode total capacity just let me put active mode is 0.009 milliampere hour, but for sleep it is 0.72 milliampere hour. I hope you are not getting confused I have used this numbers I have used this table and I got this table from this nice little graph which nice little view gra new diagram that I drew. So, I am connecting this to this and to this I said I am using a 500 milliampere hour battery and we made assumptions of the leakage of this battery as well and I use this assumption of one percent as the self-discharge and just to give you keep giving you flavors I just took battery efficiency with 300 milliampere hour, and I said 60 percent and I gave you this number and for this table which I drew I have taken an example of 500 milliampere hour.

So, this will sort of connect you into several things that we are actually doing in this process good total capacity active mode is over sleep mode is over all that is fine, what about self-discharge now is the tougher part. Now is the you have to account for the self-discharge and let me give you the number this is 5 milliampere hour right. So, you see its biggest impact on the battery life is neither the sleep current nor sleep capacity due to the sleep or due to active mode, but indeed the fact that the self-discharge is the one which seems to be over rolling, and really threatening you to can you achieve this possible that will be the question right that will be the question for you.

So, one thing that occurs to me is you can perhaps sort of let us say how to improve the battery life. So, there is any other way back to life how we will you improve how do you improve it given all these pictures, how do you improve it right. One thing to sort of improve is you increase the sleep duration in other words expand this part keep it much more expanded move it little more that sort of seems to indicate that it can improve battery life.

Why because during the intervals of active current we will no longer be contributing to the major contributor of the battery life. So, that is one thing that I can think of on the overall lifetime improvements one nice way of tall nice in terms of the theory that I spoke to you about how you calculate battery life and all that. It is also true that you can do all of what I said in the lab and you can actually capture all this with a simple current probe and an oscilloscope ok.

In fact, cheaper versions of current monitors are available, you can buy them or you can use measurement of current though drop across a resistor basically you still use a oscilloscope with a probe and measure voltage, but you basically measure using across a let us say one ohm resistor that is also another possibility. So, the many ways by which you can actually measure current what we did in the lab was to basically capture in a embedded node and IoT device for its current profile and let us see how good is that current profile from the nice picture I drew, about the about the sleep and the active time periods and the numbers I cooked up from different places to give you and feel of sleep in current being one of the dominating parts as compare to active, and also telling you about the fact that self-discharge is a very important thing.

Let me draw your attention to this measurement done by my colleagues in the lab this one you can see is say this.

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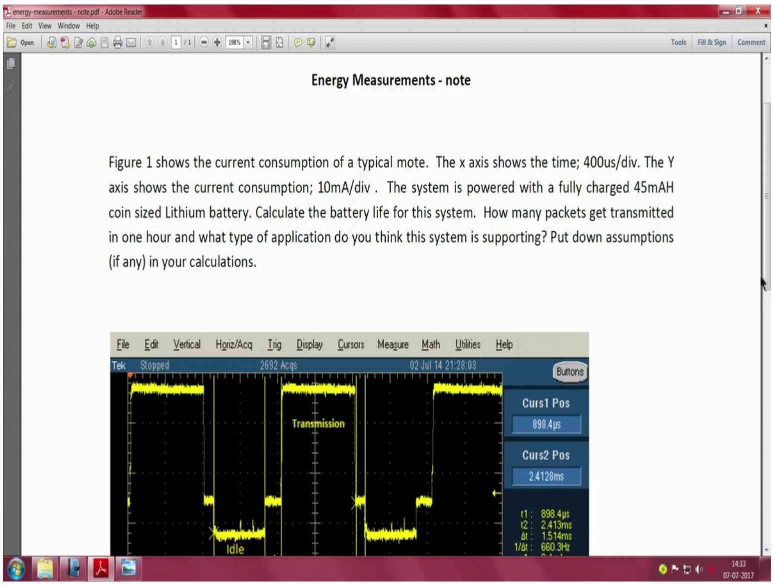

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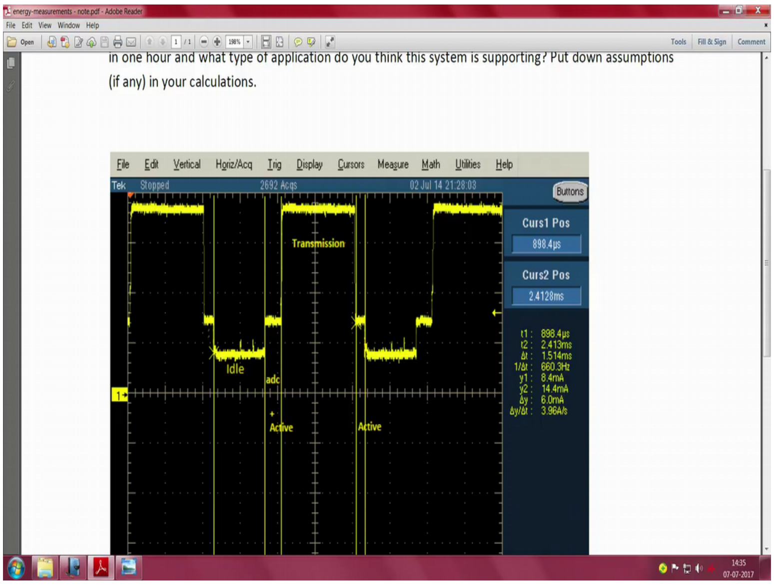

Figure one shows the current consumption of a typical node it could be an IoT device, the x axis shows the time 400 microseconds per division the y axis shows the current consumption which is 10 milliamperes per division. The system is powered with the fully charged 45 milliampere hour coin sell coin sized lithium battery. You are now expected to calculate the battery life for the system not only that assuming that this is using let us say 15.4, I triple e 15.4 technology for transmission you may even want to ask the question how many packets get transmitted in one hour and what type of application do you think the system is supporting. If you have any assumptions you can actually put down those assumptions in all your calculations, I am not going to solve this problem for you, but I am just showing you that this is actually done in our lab and let us let me just explain this picture.

So, that you will be able to connect to making this measurement possible, you can see that quite like what I drew with respect to sleep and then active period which was very I would say abstracted this is reality. The first part is indeed the transmission here that you see then it is going to one other mode, perhaps it is going to a lower current mode which could be reception mode like you do a transmission at the highest possible transmission power it could even be pus 20 d b m, and then you get a highest peak transmission is done for a certain duration which is perhaps all the numbers are on the right side. So, you can look up those numbers it is done for a significant amount of time, then you wait for a small duration which is here which is for getting an acknowledgement, the reception of the acknow reception current of for putting the state machine for keeping the state machine in reception mode is lower compared to that of the transmission here and it is also waiting for a very short duration.

Then it goes to an idle period and then goes back into sending out the next packet and then the next packet I appears that this three transmissions that you see back to back need not correspond to zombie. It appears that this actually corresponds to Bluetooth low energy where there are three packets being sent out back to back on the three broadcast channels of ultra-low power radio Bluetooth low energy radio, but never mind. In fact, I started by saying zigbee, but I am showing you this picture. A clear indicator that if you do this kind of current capture you can actually find out what is roughly the kind of technology there is being used as well of course, you can do lot of tweaks in the software code, but you can quickly also say what kind of a program has been written and you can actually check your software code for its correct functioning, by just looking at the current waveform ok.

So, you have transmission then perhaps reception and may be even its pairing mode its possible that it is also doing a pairing mode it is heard to say what exactly is this part here it is little heard to say what exactly is here, but definitely idle a d c and active state in its active state are indicated here it could be that this is just the active state and no a d c, but this could be just it could be a combination of active plus a d c here then there is a transmission and this cycle repeats.

So, please do apply what we just discussed with respect to milliampere hour, do use your calculations by taking 45 milliampere hour as the battery capacity. I would not tell you more than this you may want to go and find out if you have a 45 milliampere hour battery you can look up. In fact, a battery series called m l 20 20 think this is from panasonic take m l 20 20 from Panasonic open the data sheet find out its normal capacity find out its actual capacity right find out its discharge self-discharge and see how long calculate the battery life and also find out how many packets can get transmitted in one hour given this kind of you know transmissions that seem to be happening. So, each there I have shown here three packet transmissions.

So, the question really is how many such packets can be transmitted and finally, what do you think is this application in it is for the; you know its application for this IoT application rather; it is what is this IoT application that essentially is this kind of a waveform is most suitable.