Design for Internet of Things
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Lecture - 30
Case Study 1 - Joule Jotter

So, now what we will do in this part of the lecture is; I have two very senior project staff with me Abhirami and Zuhaib, who are working with me for sometime on a very pet project of ours and that is related to a energy monitoring. So, let me go back and write a block diagram for you.

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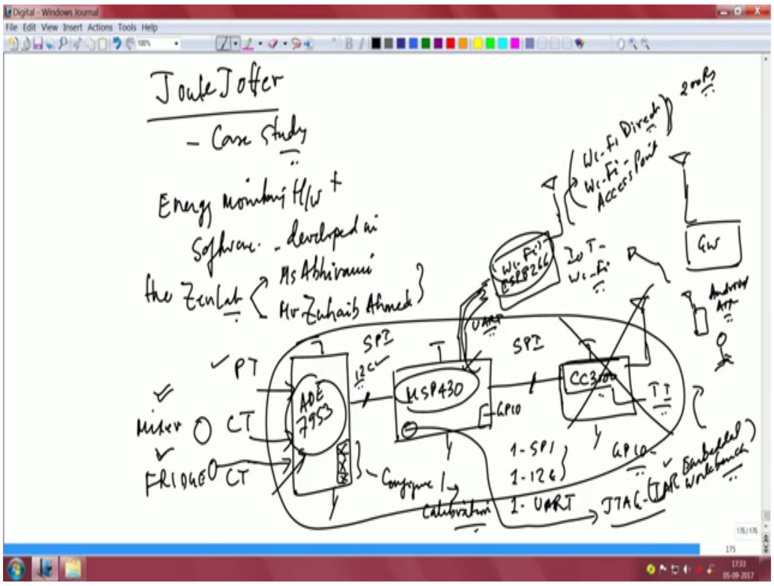

Joule jotter j o u l e; joule jotter is our case study and what is this case study all about we are trying to show you a complete run through of the code base developed for this energy monitoring hardware plus software developed in the lab; developed in the zen lab and as I mentioned to you Miss Abhirami and Mister Zuhaib Ahmed were involved in this project and are very passionate about this project. So, what does this hardware actually comprise of this hardware I will just point you to this piece.

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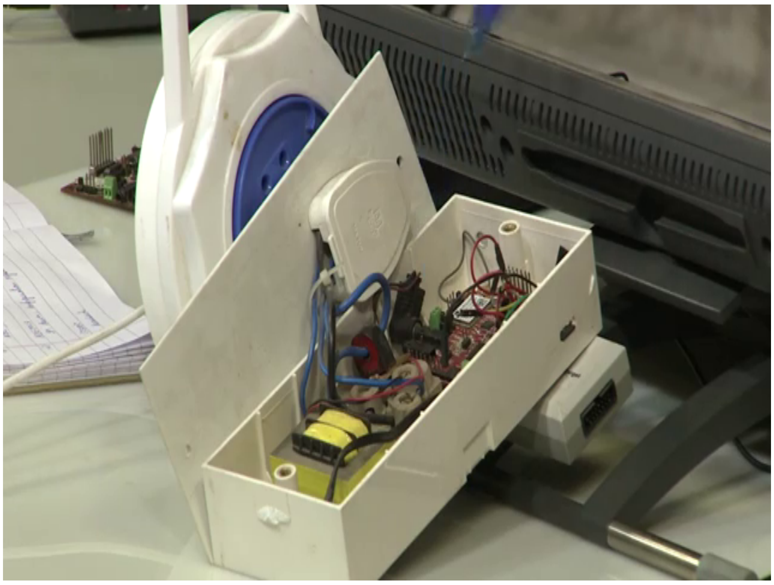

Of hardware that was developed its still in prototype stage, look here what you see here is a normal 220 volt plug extension box. Let us say there are many loads connected to this extension box and you are interested in measuring the VRMS, IRMS power output power factor all these related parameters of that plug point, you are interested in different loads. So, loads you want to completely characterize the power consumption of the load essentially you will end up with some time series data; how voltage varies over time, how current varies over time, how does power factor fluctuate over time, how does VRMS and IRMS look and all of that.

So, let us get to that slowly step by step, but before that let me point you to different elements which is part of the product that was developed in the lab. So, what I can show you here is that this is a basic from 220 it is a step down transformer, it has two tappings one tapping is to provide what is known as a PT input. So, if you take transformers the sensors which are required for measurement of these electrical parameters, you need what is known as a PT. PT stands for potential transformer, CT stands for current transformer.

So, this transformer that you see here has two tappings one is it works like a sensor for energy monitoring and it also works as a transformer for powering the electronics the electronics is here I will show you the PCB in a little bit detail what you see here this component here is the c t which is the current transformer for measurement of all current related to in order for you to get the current time series you need this in order to get the voltage time series you need.

You need to get to the PT and the full electronics system is here let me show you again this circuit this PCB against the camera and let us zoom in a little bit.

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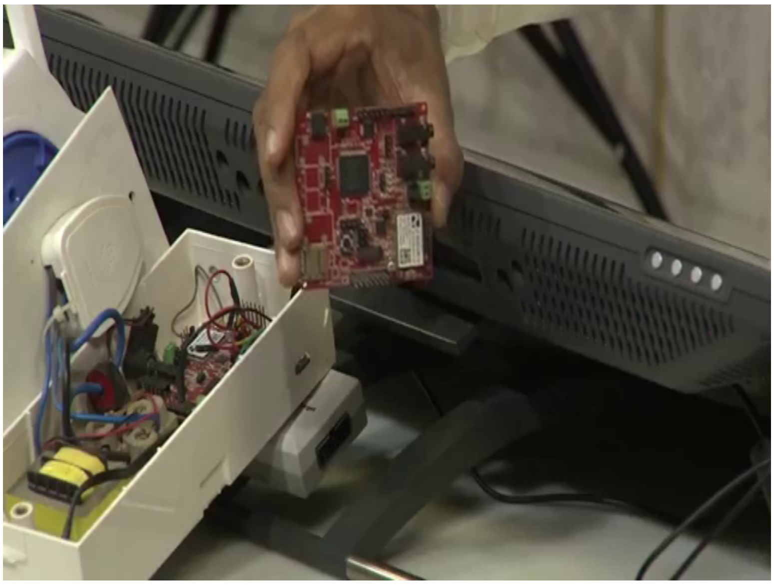

Let us try and zoom in a bit closer to see what are all the different elements which are there in this board, you can see that this massive looking chip here a little more closer please. So, this big one this big chip here is the micro controller this is MSP 430. So, let me write it down for you. So, the controller of interest is MSP 430 F 5438A. Look at the packaging information QFP package not QFN its QFP this is QFP quad flat package right that is the chip here this system that you see here this is indeed the radio module this is called CC 3000 for some reason this radio module gave us some trouble we will discuss that interface to this radio module separately. So, just to complete the schematic capture as we go along I will write MSP 430 like this and I will connect the CC 3000 through a disconnected through a SPI bus right this is connected through an SPI bus.

And this is the radio module CT and PT are connected here. So, this is the MSP then what else do we have on this board; obviously, it has to be powered. So, you need a rectifier chip. So, you can see this is the rectifier chip then input AC input is fed through here after stepping down in appropriate manner there is an LDO here, the LDO is here LDO is C in and C out capacitors are here this is the C in capacitor this is the C out capacitor let me hold it for you, this is the C in and this is the C out capacitors of the LDO and what else.

So, these are the two channel inputs that this energy monitoring chip can do, which means the inputs obviously, cannot go into MSP 430 because it is a controller it uses a microcontroller system. So, I am actually going to replace this with ADE 7953 which in turn is connected to the MSP 430 and MSP 430 u turn connected to CC 3000 and CC3000 providing you the radio and this is an SPI module. So, you can see this is indeed the right schematic as we develop the story we realize that CT PT have to go to a energy monitoring chip from analog devices and this chip is again there is a requirement for another I2C here.

Now if you are asked to choose this microcontroller you obviously, have to choose something that can support at least 1 SPI and one I2C. So, right clearly MSP 430 is a good choice for this because it does support these things this ability of having I2C as well as an SPI bus, and this controller itself this energy monitoring chip itself will have an internal controller which can several things for you; obviously, when you want to gather data over an I2C bus this ADE 7953 will have a number of registers which you have to configure for the purposes of calibration therefore, we should see that part of the code how MSP 430 which is the controller of choice is actually able to pass commands to ADE 7953 and configure some of the registers inside the energy monitoring chip.

As I mentioned to you our final working circuit for a long time although used to CC 3000 we then shifted out to support the radio communication over a very popular Wi-Fi module called ESP 8266. So, this part was removed. In fact, it will continue to be there, but you just do not use this all the data all after all the acquisition is done it is given to this module over a u art code. Now if you ask yourself this question how will I choose a controller, it is insufficient to say I need one I2C and one SPI, but I also need one u art right. Now you also need sufficient amount of programming pins if you are interested in using pins if you want if you do energy monitoring and you want to do an actuation, you will definitely need a number of GPIO lines in order to control perhaps lighting load or relays and so on.

So, a number of GPIO pins are also required. So, you have to choose a controller which will support all these peripherals peripheral support as well as support for communication over very popular Wi-Fi modules which is typically like ESP I266. Now I struck this off because this is a very early module from TI they have improved versions of this chip although we did not want to change anything this was one of the first IoT Wi-Fi module and it you know as the chip was not very stable we had to apply a number of patches in order to ensure that it would work satisfactorily very soon what would happen is it would hang. So, communication between the gateway and this unit by itself was often a buggy situation. So, we had to shift to another popular one and indeed this is a very popular IoT Wi-Fi module which we will try and see.

We can spend some time understanding. In fact, Zuhaib has spent considerable time trying to tune this Wi-Fi module for communication. Essentially this Wi-Fi module supports both Wi-Fi direct which is peer to peer Wi-Fi, and it also supports like a Wi-Fi hotspot access point. So, it is a very popular one which is available for about 200 rupees we should be able to buy it and it is a Chinese product I think from Shenzan and a very popular module, but available locally. So, one could easily use it.

So, this is in brief the hardware let us shift quickly to some good aspects of this of the software architecture of this of this module just to give you a feel of how one can develop hardware products in a IoT how you can actually build IoT products for several applications. In this case this is specific to the energy monitoring hardware all right. So, you can see that you have to program this MSP 430 right. So, you need a J Tag port for that, J Tag and on J Tag we use this tool called IAR work bench it is a very powerful you know environment under which one can develop code for MSP 430 different targets are available and for we have chosen MSP 430 as a target processor and this is available. So, we have used IAR work bench for all the code development that is one part.

Then finally, what you also need is an android app right whereby users should be able to hold a phone, and get their data not only get data, but also configure this their home devices right because we mentioned that there are 2CT channels and 2 loads can be connected home loads one could be a washing machine and the other one could be let us say let me take a example in the kitchen that is much simpler one could be a mixer, mixer grinder and the other could be a refrigerator fridge I will call it simply fridge.

Both these systems we want to monitor and you actually want to configure and say this is the mixers joule jotter and fridge system that I have this is the complete system that I have this system I will just circulate like this and say this hardware is for mixer and for fridge you want to configure right. So, all of that you should be able to do as a end user using a simple android app and that android app should be quite friendly you know and those commands should be configurable through this Wi-Fi module. So, in other words the Wi-Fi the smart phone which also has a Wi-Fi is used to configure the devices which are connected. So, that is a nice that is another requirement in order to make your in order to builds your IoT products.

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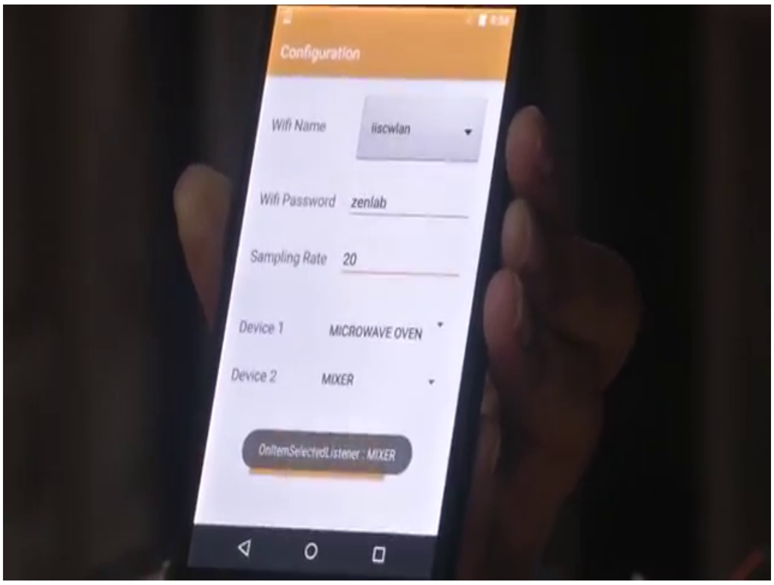

So, let us see how this acts the android app works with the joule jotter the joule jotter android app. So, let us go there and click on it you will see that Zenlabs joule jotter app opens, there are three possible configurations three possible options here configure leave it a default and collect data and perhaps see data. So, visualize data let us go to configure data and here you can see you can specify the Wi-Fi name that you want to, connect to go down you can choose the Wi-Fi name right and let us choose ISCWlan you can set the password, you can set the sampling set the password to something there and then you can set how many samples you need in one minute, let us say no you need every 20 seconds this is every 20 seconds, you will get a sample of all the parameters that the chip can monitor this is a so that means, you get 3 20 seconds you get one.

So, in 1 minute you get 3 samples of IRMS, VRMS power factor then average that is peak power and other related parameters and then you can give the name for the two devices you want to connect, you have device one which can be refrigerator, t v whatever you want to configure and let us say microwave oven or a mixer. So, microwave oven and mixer are mixer grinders are typically those which are inside kitchen. So, you just type all that and then just press configure button.

It configures and then connects to the system and essentially passes all these parameters onto the joule jotter piece of hardware.

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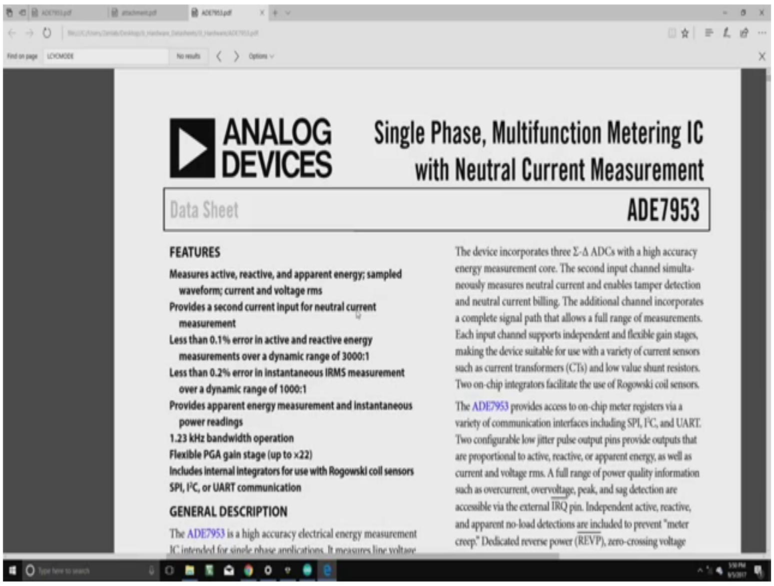

So, let us go back and look at how should we go about working with this joule jotter in order to get our IRMS, VRMS, output power, power factor so on and so forth. The heart of the hole joule jotter indeed is this chip called ADE 7953 you can see it is a single phase multifunction metering IC, and it has a number of features you can see that it has one of the important things it has less than 0.1 percent error in active and reactive energy measurement, provided you do adhere to the datasheet in its proper manner in its proper way.

You have to calibrate registers, you have to calibrate the equipment using standard equipment you know to calibrate the joule jotter with standard equipment only then it can give you assurances of 0.1 percent error. It also says that 0.2 percent less than 0.2 percent error in instantaneous IRSM measurement is possible again this always means that you have calibrated the IC properly at the time when you boot the system you have to ensure that you have calibrated correctly.

It has a bandwidth of 1.23 kilohertz for all its operation and you can use different type of sensors including what is known as a Rogowski coil sensor for the measurement of current for accurate measurement of current of course, this would mean that an additional piece of hardware is required, but that is beside the point.

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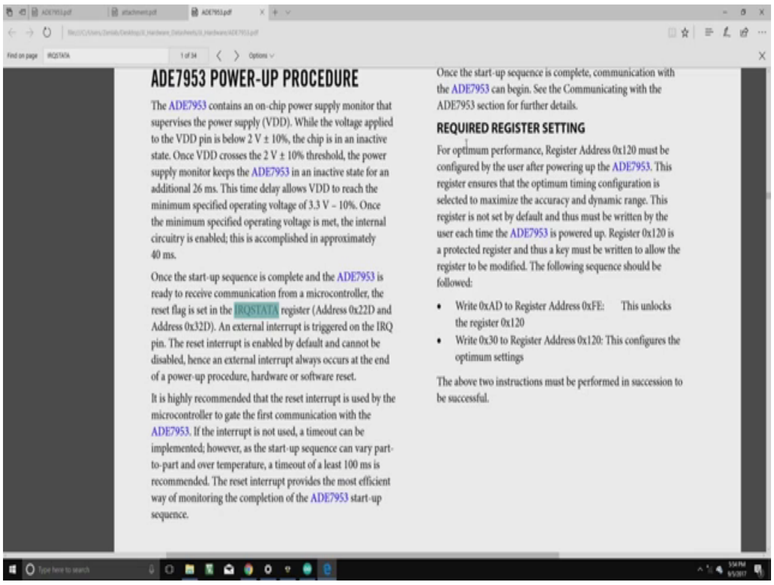

ADE7953 POWER-UP PROCEDURE

The ADE7953 contains an on-chip power supply monitor that supervises the power supply (VDD). While the voltage applied to the VDD pin is below 2 V ± 10%, the chip is in an inactive state. Once VDD crosses the 2 V ± 10% threshold, the power supply monitor keeps the ADE7953 in an inactive state for an additional 26 ms. This time delay allows VDD to reach the minimum specified operating voltage of 3.3 V − 10%. Once the minimum specified operating voltage is met, the internal circuitry is enabled; this is accomplished in approximately 40 ms.

Once the start-up sequence is complete and the ADE7953 is ready to receive communication from a microcontroller, the reset flag is set in the IRQSTATA register (Address 0x22D and Address 0x32D). An external interrupt is triggered on the IRQ pin. The reset interrupt is enabled by default and cannot be disabled, hence an external interrupt always occurs at the end of a power-up procedure, hardware or software reset.

It is highly recommended that the reset interrupt is used by the microcontroller to gate the first communication with the ADE7953. If the interrupt is not used, a timeout can be implemented; however, as the start-up sequence can vary part-to-part and over temperature, a timeout of a least 100 ms is recommended. The reset interrupt provides the most efficient way of monitoring the completion of the ADE7953 start-up sequence.

Once the start-up sequence is complete, communication with the ADE7953 can begin. See the Communicating with the ADE7953 section for further details.

REQUIRED REGISTER SETTING

For optimum performance, Register Address 0x120 must be configured by the user after powering up the ADE7953. This register ensures that the optimum timing configuration is selected to maximize the accuracy and dynamic range. This register is not set by default and thus must be written by the user each time the ADE7953 is powered up. Register 0x120 is a protected register and thus a key must be written to allow the register to be modified. The following sequence should be followed:

- Write 0xAD to Register Address 0xFE: This unlocks the register 0x120
- Write 0x30 to Register Address 0x120: This configures the optimum settings

The above two instructions must be performed in succession to be successful.

Let us now go to a very important part which is the register settings of this IC I want to point you out in this datasheet to a register called IRQ stata. Now look at what it says about IRQ stata once the startup sequence is complete and ADE7953 is ready to receive communication from a controller microcontroller, the reset flag is set in the IRQ stata register right. An external interrupt is triggered on the IRQ pin the reset interrupt is enabled by default and cannot be disabled hence an external interrupt always occurs at the end of power up procedure hardware or software reset. Let me show you in the code the point where IRQ stata is actually this particular register setting is actually enabled.

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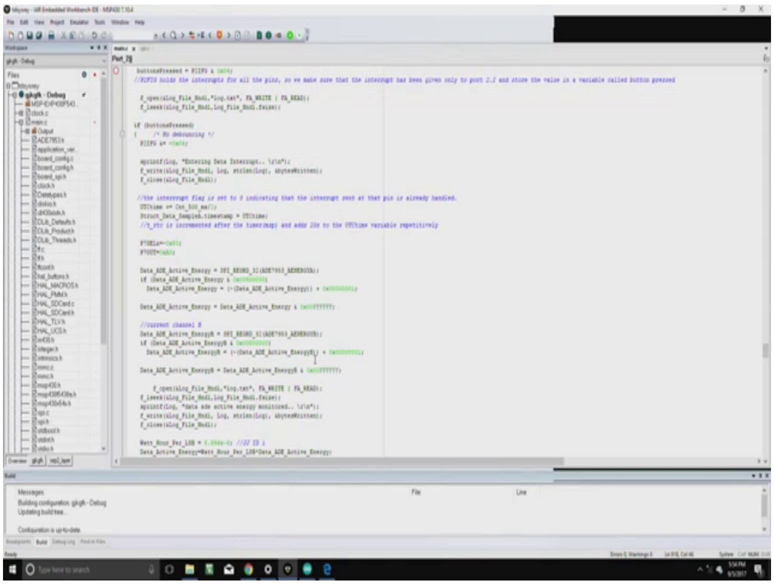

So, let us go there to that part of the code as you can see this is IAR workbench, IDE let us increase the size if required so that you will be able to see them a lot more clearly I think we should show that a little. So, there you are. So, you can see that IRQ stata register SPI register read 32 bits for ADE7953 IRQ status from current channel a right there are two channels as we disrupt, IRQ stata A and IRQ stata B maybe the second one. So, this is how you would actually write you would actually configure do a register setting.

Let me now also point you to other important registers gone back to the datasheet. So, what are we trying to do here you have to read the datasheet go back and implement it in source code that is the key point here.

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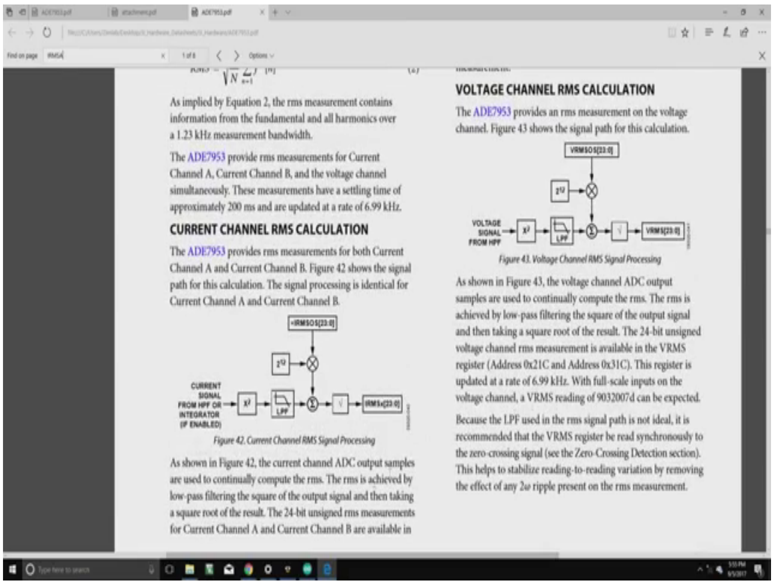

Let us go to IRMS A as a possible as one of the other register setting. Here the IRMS a register says that this is a 24 bit unsigned RMS measurement for current channel A and current channel B available in this (Refer Time: 22:20). So, if you are interested in reading IRMS from channel A you have to use this register the values stored in this register.

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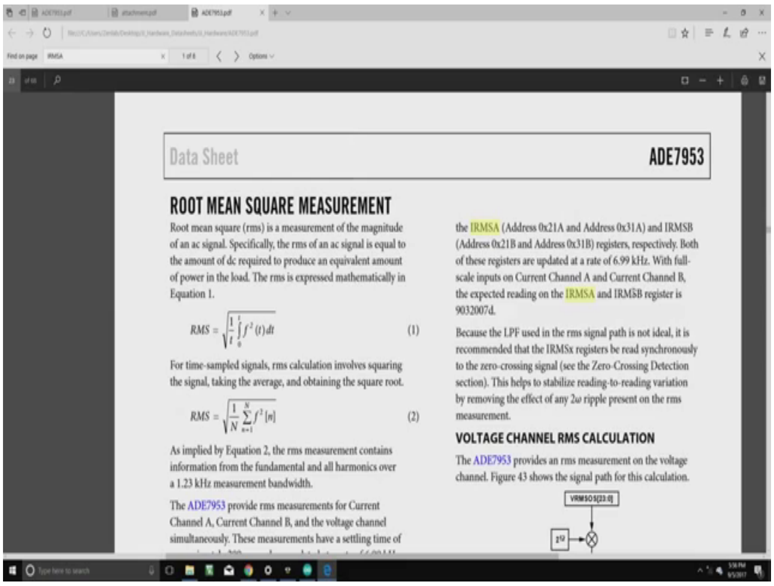

Now let us go and see. So, what should happen both of these registers are updated at what rate at 6.99 kilohertz per second kilohertz at this rate they are updated with full scale channel inputs on current channel A and current channel B, they expected reading of IRMSA and IRMSB register is some value. Now let us go back and see what exactly how exactly this is done in source code.

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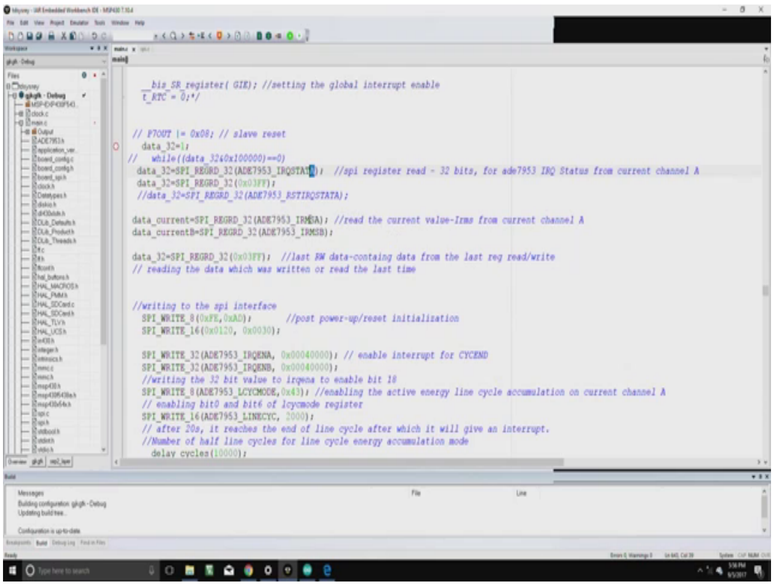

You can go back and see here that SPI read 32 bit for a d e i r the IRMSA read the current value IRMS from current channel A. So, you can see data current underscore current is equal to SPI register read underscore 32 ADE7953 underscore IRMSA right. So, if you do this you are actually reading the IRMSA register this is a 32 bit register and this 32 bit register is being read similarly you can be talking about IRMSB and so on. Let us go and look at IRQ ENA.

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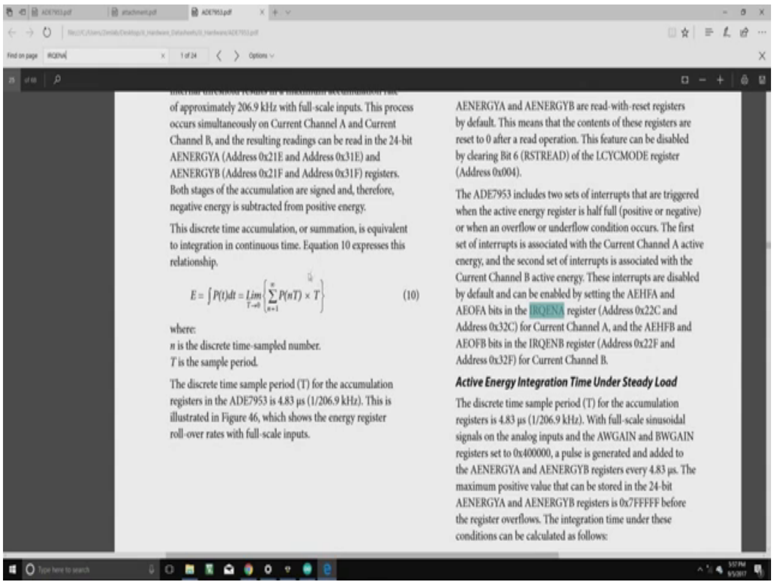

Let us look at IRQ ENA and let us see what actually this does.

T his is IRQ enable a right. So, these interrupts are disabled by default and can be enabled by a e h f a and a e o f a bits in the IRQMA register. This is each this register multibit register has a name for each bit position, a e h f a and a e o f a are two bit positions in the IRQNA register right and that address is mentioned there for current channel a and current channel b. Let us go back and look at these two IRQNA B in source code you can see that SPI right underscore SPI underscore right underscore 32, ADE7953 underscore IRQNA right and IRQNAB.

So, the big summary here is that you will have to look at the datasheet and accordingly write your code in an appropriate manner and debug your code, let me point you to the top extreme left here which says that this debugger that we are using environment software environment tool indeed is the IAR embedded workbench IDE for MSB 430. Your problem does not end here actually you have to do in order to accurate values and try to meet the datasheet requirements you also have to do calibration of some of the registers, that again is another document.

Now, let us go and open up that document and read this starting part of the document. It says calibrating a single phase energy meter based on ADE7953.

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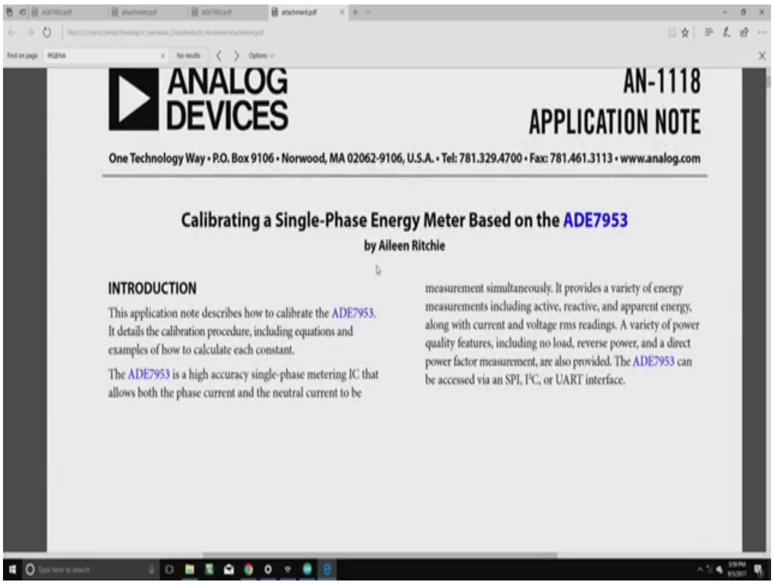

What it simply says is application note describes how to calibrate ADE7953 it details the calibration procedure including equations and examples on how to calculate each constant. ADE7953 is a high accuracy single phase metering IC that allows both phase current and neutral current to be to be measured simultaneously. It provides a variety of energy measurements including active reactive and apparent energy along with current and voltage RMS readings. A variety of power quality features including no load reverse power and a direct power factor measurement are also provided right.

Let us see; what are the calibrations that you have to do down below if you go and browse through this document.

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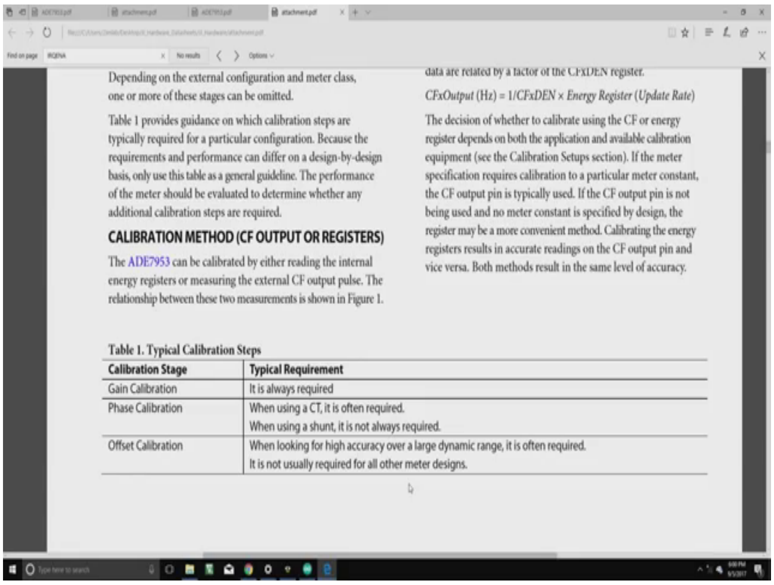
Depending on the external configuration and meter class, one or more of these stages can be omitted.

Table 1 provides guidance on which calibration steps are typically required for a particular configuration. Because the requirements and performance can differ on a design-by-design basis, only use this table as a general guideline. The performance of the meter should be evaluated to determine whether any additional calibration steps are required.

CALIBRATION METHOD (CF OUTPUT OR REGISTERS)

The ADE7953 can be calibrated by either reading the internal energy registers or measuring the external CF output pulse. The relationship between these two measurements is shown in Figure 1.

data are related by a factor of the CFxDEN register.

CFxOutput (Hz) = 1/*CFxDEN* × *Energy Register* (*Update Rate*)

The decision of whether to calibrate using the CF or energy register depends on both the application and available calibration equipment (see the Calibration Setups section). If the meter specification requires calibration to a particular meter constant, the CF output pin is typically used. If the CF output pin is not being used and no meter constant is specified by design, the register may be a more convenient method. Calibrating the energy registers results in accurate readings on the CF output pin and vice versa. Both methods result in the same level of accuracy.

Table 1. Typical Calibration Steps

Calibration Stage	Typical Requirement
Gain Calibration	It is always required
Phase Calibration	When using a CT, it is often required. When using a shunt, it is not always required.
Offset Calibration	When looking for high accuracy over a large dynamic range, it is often required. It is not usually required for all other meter designs.

Gain calibration phase calibration and offset calibration are the most important things here. So, gain calibration as it says it is always required, phase calibration when we are using CT in which case we are it is often required, and when using a shunt it is not always required. Offset calibration perhaps when looking for high accuracy over a large dynamic range it is often required, it is not usually required for all other meter designs. So, in a way offset calibration may not be so critical when you are measuring pluggable loads smart in homes, but gain and phase calibration definitely you have to do. Let us now go back and look at the source code and look at these calibration resistors which are done in the source code.

Let us look at gain calibration to begin with. So, you can see that gain calibration is ya you can see here i calibration v calibration are all part of the; i calibration has a has a number there which you have to prime into the register, v calibration also has a number and these two numbers are actually available from that other datasheet that we went to and these are configured here. So, gain calibration phase calibrations are important and they have to be done.

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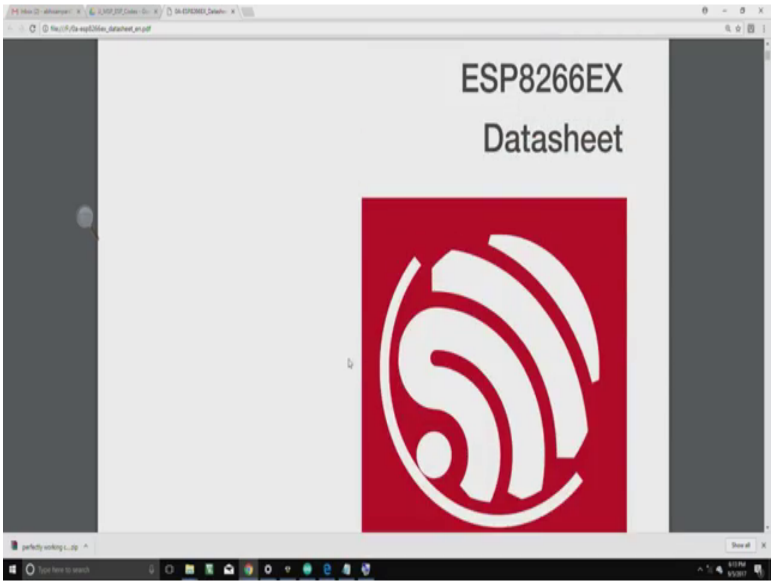

Let me introduce you to this very exciting chip this is called ESP 8266 EX and this is the Wi-Fi module that we have used in our joule jotter hardware, after we bypass the existing CC 3000 Wi-Fi module right because it was buggy and so many other issues were there. This ESP 8266 actually has complete t c p i p stack embedded stack running on it and its some of the good features of this chip are that it supports standard Wi-Fi protocol 802.11.

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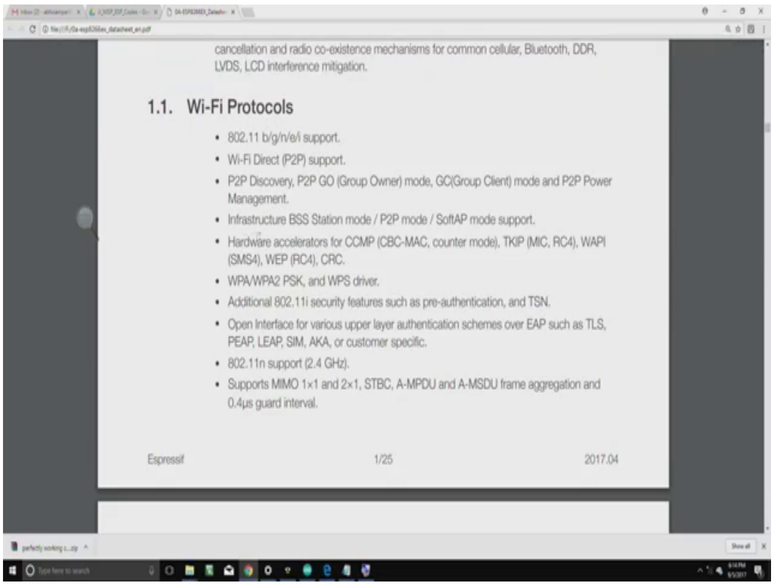

Many versions b g and e i and all that it does Wi-Fi direct peer to peerm support it does peer to peer discovery, you could have it as a group owner or as a group client in this peer to peer mode, it can work as a in the infrastructure mode it can be configured as an access point and it has security beautiful security features CCMP CBC MAC TQ CRC all of that which means it is indeed a chip which is a embedded chip embedded module, but very powerful has all the security features embedded net and it is as I mentioned already has a TCP IP stack running on it, it is just not working for not just working as either peer to peer Wi-Fi direct access point, but it can also be used for range extension purposes which essentially is for repeater functionality.

So, many nice features are possible on this using this module so; however, look at the before we go onto that.

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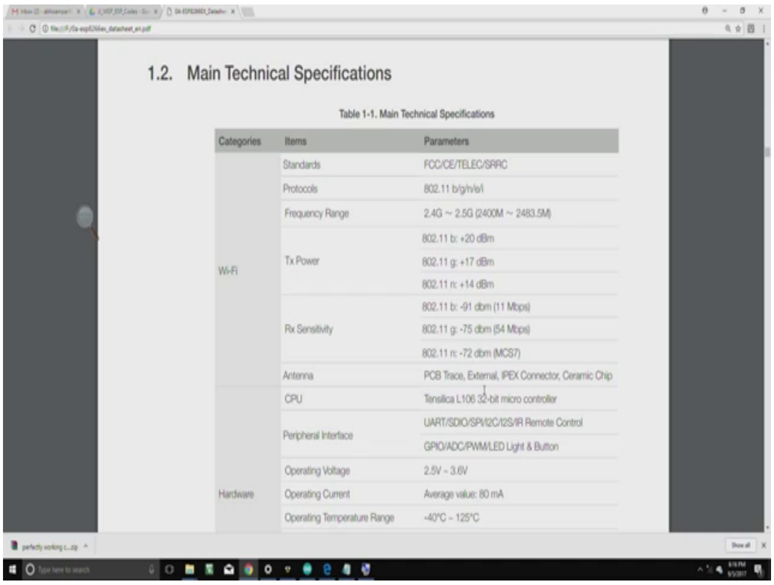

1.2. Main Technical Specifications

Table 1-1. Main Technical Specifications

Categories	Items	Parameters
Wi-Fi	Standards	FCC/CE/TELEC/SRRC
	Protocols	802.11 b/g/n/e/i
	Frequency Range	2.4G ~ 2.5G (2400M ~ 2483.5M)
	Tx Power	802.11 b: +20 dBm
		802.11 g: +17 dBm
		802.11 n: +14 dBm
	Rx Sensitivity	802.11 b: -91 dbm (11 Mbps)
		802.11 g: -75 dbm (54 Mbps)
		802.11 n: -72 dbm (MCS7)
	Antenna	PCB Trace, External, IPEX Connector, Ceramic Chip
Hardware	CPU	Tensilica L106 32-bit micro controller
	Peripheral Interface	UART/SDIO/SPI/I2C/I2S/IR Remote Control
		GPIO/ADC/PWM/LED Light & Button
	Operating Voltage	2.5V ~ 3.6V
	Operating Current	Average value: 80 mA
	Operating Temperature Range	-40°C ~ 125°C

Let us look at the r x sensitivity receiver sensitivity it is down to minus 91 dBm if it is b, if it is g it is minus 75 dBm and n is minus 72 dBm. So, and it works in this nice voltage range operating voltage range is 2.5 to 3.6 all right. So, essentially as I mentioned it is it has support for embedded TCP IP stack mainly it supports IPV 4. So, that is perhaps one limitation of this system.

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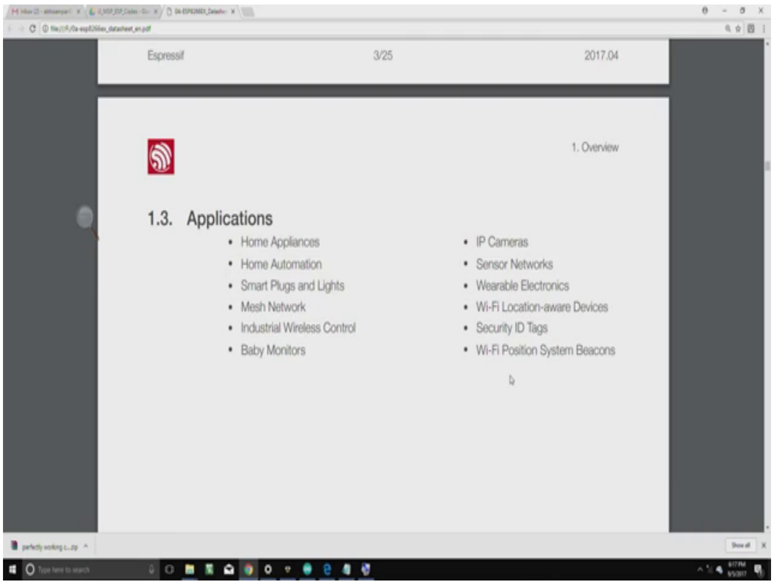

And newer modules with IPV 6 stack are also expected to come nice applications possible home smart plugs lights mesh network baby monitors IP cameras sensor networks and so on. Really a good Wi-Fi IoT module for several application many many YouTube videos are available for this very exciting ESP 8266 Wi-Fi module; however, if you put it into the framework of what we did in the joule jotter prototype hardware, we now ended up with another type of you know IDE framework which essentially I want to draw your attention to this screen which is which essentially talks about the Arduono IDE right.

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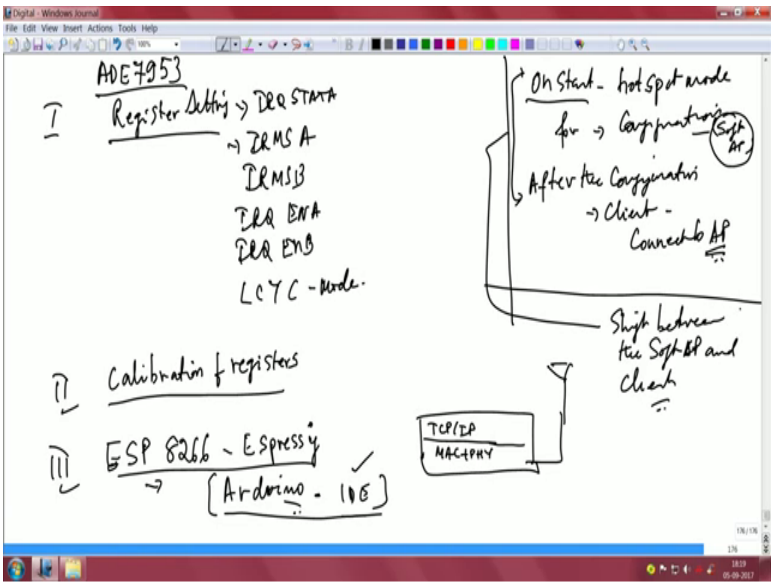

So, it is. So, now, you can see all the ADE configurations that we did earlier used IDE used IAR work bench for configuration, and only for the purpose of configuring the Wi-Fi chip we had to shift to the arduono IDE. Now there is something interesting that we have configured this chip and trying to use its power, if you cold start the joule jotter I mentioned to you that we need a android app for configuring several parameters right and that essentially means you are in the soft AP mode the ESP module is put into soft AP mode and users can type in the parameters of interest like device names sampling rate and all that you can use it you can use this ESP in the hotspot soft AP mode soon after the configuration is completed the module joule jotter module can connect to your home gateway can your connect your home gateway access point.

In other words you can shift between very seamlessly you can shift between the soft AP mode and client. I just want to show you that piece of code which will allow us to which we have written developed in the lab which will allow you to move between the two. Let us first expand the screen such that there is some legibility in terms of the mode that we want to show that is between soft AP and as a client.

If you look at that setting which has been marked in highlighted part the Wi-Fi dot soft AP are not able to show you clearly if it can be expanded configuring as access point, you can see that it is actually being configured as the soft Wi-Fi soft AP and so this is the mode in which users can fill in all their parameters from a end users perspective then it can also be configured for the client purpose and that part indeed is perhaps another method which the lab development takes place and this is the method to connect to a Wi-Fi access point as you can see right here it is called void Wi-Fi and then this particular thing indeed connects to the SSID perhaps announced in your homes.

So, very powerful, interesting chip IoT chip Wi-Fi chip for several applications.