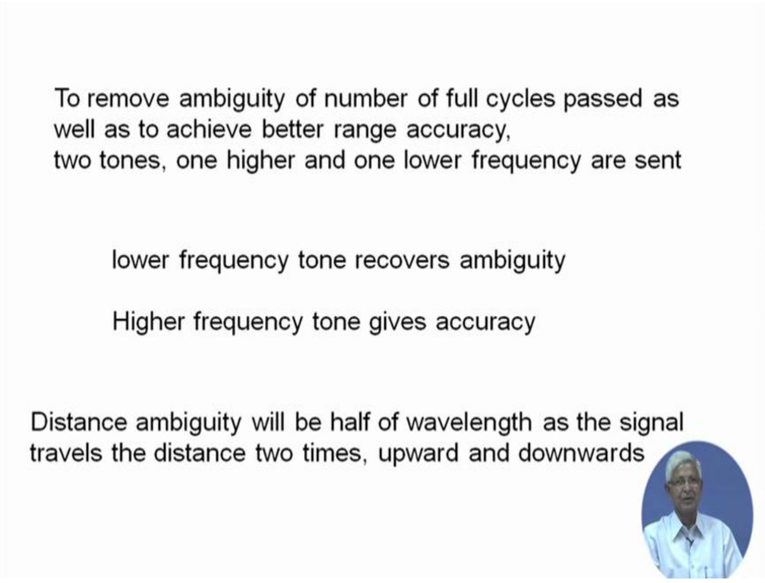
Satellite Communication Systems
Prof. Kalyan Kumar Bandyopadhyay
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 08
Space Segment-3

Welcome. We will continue our discussion on space segment particularly the bus of the satellite. And we are already discussed the attitude and the arbitrary control system AOCS and then we came to delibatery, telecommand and tracking and out of that we have covered telemetry and telecommand briefly and we are discussing about tracking.

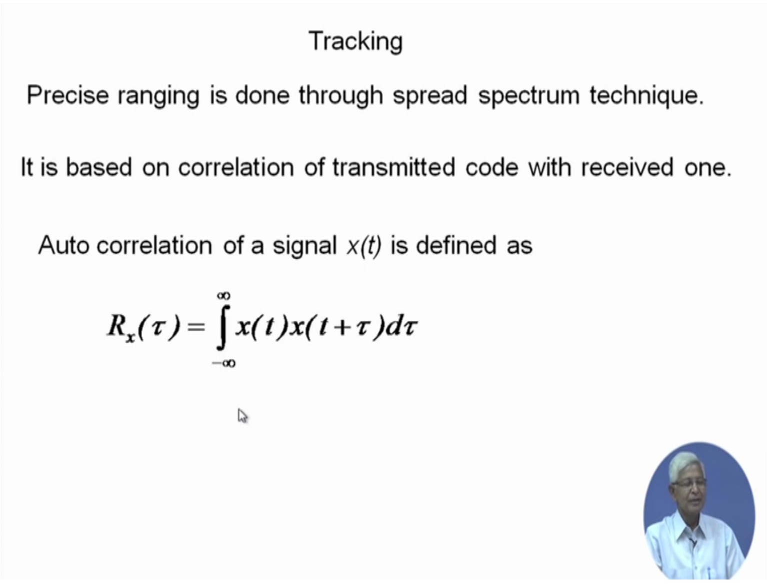
(Refer Slide Time: 00:45)



So, just recollect we said for the tracking there is some problem we are facing that is we when we sent tone we will get certain ambiguity in number of full cycles that has passed which we do not know, we do not know that count. So therefore, a lower frequency tone is required so that a full cycle covers the up and down range that is two times the range.

But then you do not get the accuracy. So therefore, a higher frequency tone is required to get the accuracy where phase is smaller. Therefore, lower frequency as well as higher frequency tone both is required, this is one the tone. But, now days in digital system we get much more precis way of doing it that is by sending some code.

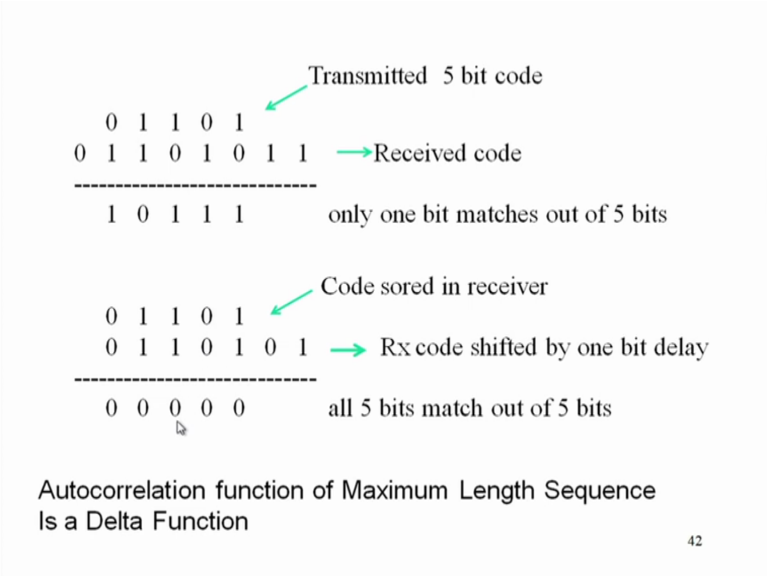
(Refer Slide Time: 01:39)



That is there is through some technique which is called spread spectrum technique something like that. So, we have a tone which is actually digital tone; let us call the digital tone. It is based on correlation; that means, certain code we send and they receiver knows the code same place the transmitter is there, so transmitted sends the code and goes to the satellite it comes back and then the code is compared with the transmitted code and the delay the code. Delay in the code in terms of how many bits that called delayed from that you can find out what is the range.

A simple way of finding is that you have a auto correlation signal that is xt and xt get delayed by tau and the locally generated code which is already stored when it is compared and that locally generated code when it is shifted by the tau amount that is in terms of delay tau amount then you get the auto correlation proper.

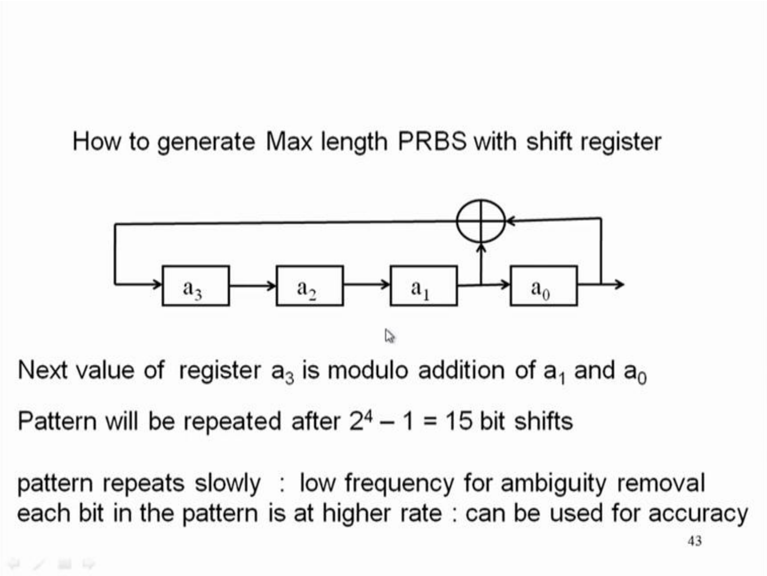
(Refer Slide Time: 02:46)



Now, in case of that I have shown as a summation is continuous process, but I can be digitized also. In the digitize format is give a simple example many of you know that but still I repeat. Let us say we are transmitting a code of 5 bit which is 0 1 1 0 1 which is transmitted. And after sometime it get back the code which is already shifted that is 0 1 1 0 1 0 1 1 like that, but at this point when we try to compare is snap short we find that correlation is happening only in one bit out of 5 bits, so only one bit has matched; that means, code has not fully match, so we at delayed. Further there is delayed by one more bit so this 0 1 1 0 1 0 1 1 it shifted further one bit now it becomes 0 1 1 0 1 which exactly matches with the transmitted code.

These transmitted codes are already stored in the receiver. With the stored register you compare the receiver code and you get 5 bit a match. So, it is like a almost like a delta function there is a auto correlation function is I can called it maximum length sequence code that is generation will see and then it is like a delta function, where it matches it gives the all match. This is exclusive or matching then modular two additions you can do it exclusive now also.

(Refer Slide Time: 04:17)

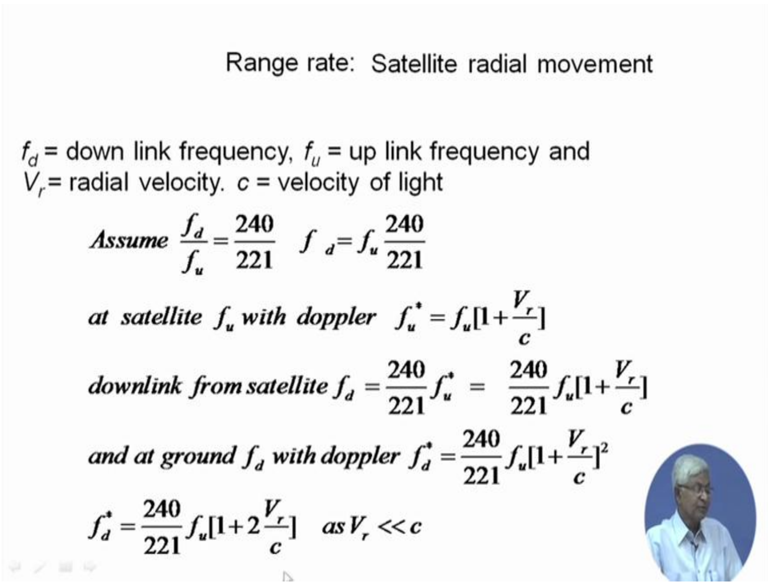


How do you generate that PRBS code with a shift register? You know the technique but still a repeat that let us say there is a 4 bit shift registered a0, a1, a2, a3 and the output of a0 and a1 is module to added and fade to the a3 shifts in the right a side direction. So, this side you will get the PRBS code.

So, the next value of a3 will be modulo two additions of a0 and a1, so like that it will continue. And it can be seen that a pattern which comes out is repeating after 15 bits there is 2 to power 4 minus 1 that is since 4 bits shift where used, it is a maximum length of pattern which generates and in between the pattern the (Refer Time: 05:09) property there is a property that bits are random. This can be used one of the advantage of this. Now at the bit rate you are sending it seems that this particular pattern is much slower than the bit rate it is 15 of such bits next this pattern. So, it is 15 times slower than the bit rate that means I can get a lower frequency tone. As if equivalent to a low frequency which can be use as ambiguity made for removal.

So, by using this number of shift register and making it maximum length shift register by properly doing modulo to addition I can make the length of the pseudo random binary sequence much much larger. So, that is a low frequency and which will remove the ambiguity. We can make it such larger that range two time the range it will be more than that. And then each bit of that is going at a particular bit rate that is at high frequency rate so that gives the accuracy. So, bit by bit if you do in it gives the accuracy. So I get both low frequencies so there is ambiguity removal and I get the accuracy are a much higher frequency. So, this is the technique which is call if it call it (Refer Time: 06:25) ranging that using PRBS spread spectrum ranging. This is one of the technique say two way ranging. There are some techniques where people do one way ranging here we have not going to discuss that, let us say see this two way ranging.

(Refer Slide Time: 06:45)



Now, there is one more thing we should consider. We find the range, but then satellite is not stable it is slightly drifting depending on the forces which are acting on it. So, you if you remember earlier our discussion there are a station keeping box that within that satellite that is all drifting depending on the push and pools which are forces which are acting on it. It may have east west north south and certain radial movement also or a component may be there which can be radiant to the center of the earth. So, there is a radial movement

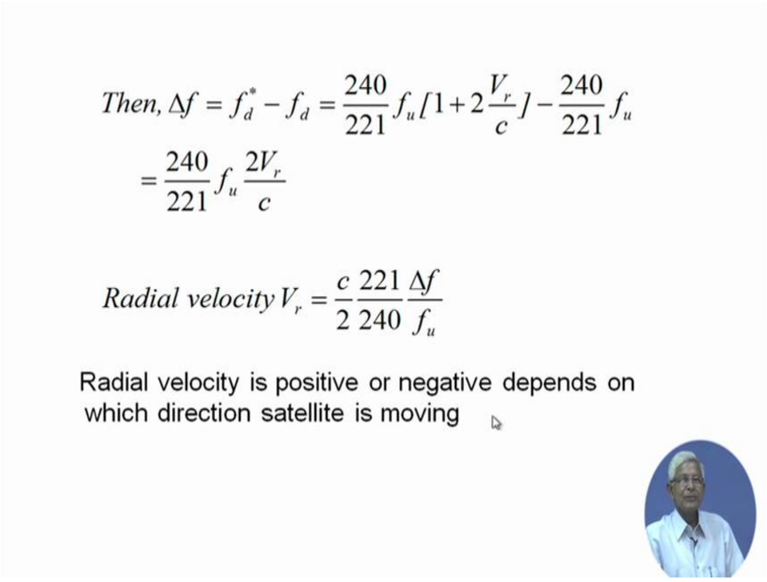
That means, when we are trying to do the range that time itself satellite is moving, so moving at a particular rate that is called range rate. So, let us try to calculate the range rate based on the uplink frequency downlink frequency and radial velocity and velocity if light. Now uplink and downlink frequencies I already mentioned earlier there is some allotted frequency so it can be put as ratio will two is some rough calculation. Let us see carefully. Let us assume the downlink frequency f d and uplink frequency f u the ratio of that is a number 240 by 221 based on the what frequencies selected here I have taken this particular number you can take the exact number on which its being transmitted and received.

Simply from this expression can find out downlink frequency is uplink frequency multiplied by the factor 240 by 221. When I do uplink at the satellite, satellite is moving, so uplink frequency will have a Doppler so that Doppler frequency. Let us term is f u star, f u star will be they f u itself plus the delta f u which is velocity in the radial direction by c; c is the velocity of light. So, it is f u into 1 plus Vr by c that is the frequency which is reaching at the satellite the original frequency plus the Doppler. Now this plus sin depends on which direction it is moving, in this case we have taken that is coming towards the earth so it is a positive direction.

Now satellite will convert these one and repeat it down to the earth so it will take this frequency and put in to has a downlink frequency and downlink frequency is uplink frequency multiplied by a factor which we are assume 240 by 221. In this case downlink frequency will be 240 by 221 this factor multiplied by the uplink frequency with Doppler that is f u star, and which is in terms of f u is 240 by 221 f u multiplied by 1 plus Vr by c. Now when this downlink frequency comes down to earth that Doppler again is happening on it, so on the station received downlink frequency will be having certain Doppler which is again 1 plus Vr by c.

So, the whole thing will be downlink frequency star which is the downlink frequency plus the Doppler is equal to 240 by 221 f u into 1 plus Vr by c Whole Square, this two times it is happening I mean it is going up and downs that is why multiplied so it is square. Now, this square means 1 plus Vr by c whole square plus 2 into here by c. Now Vr radial frequency is very small compare to the velocity of light. So therefore, you can neglect that Vr is very small compared to see of Vr by c whole square can be neglected. In this the term will be f d size go to 240 by 221 f u into 1 plus 2 times Vr by c.

(Refer Slide Time: 10:39)

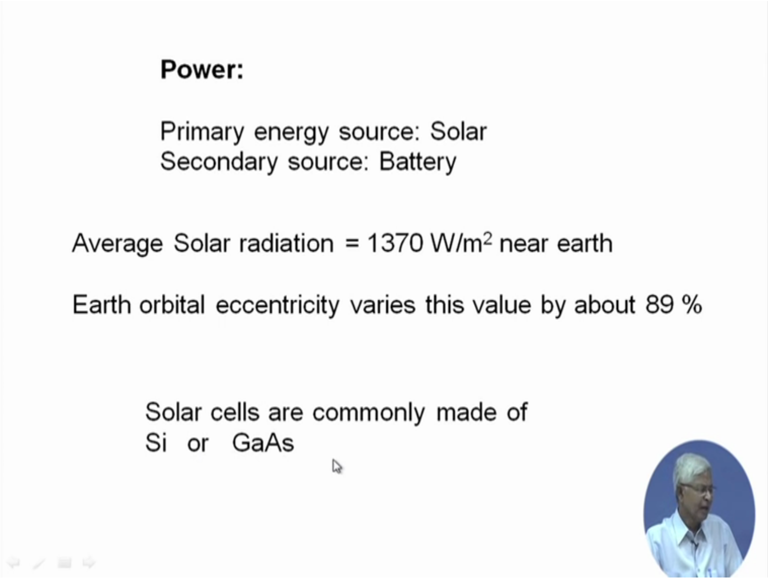


Then the downlink Doppler that is the receiver earth station is seen that is delta f will be f d star minus the downlink frequency what is suppose to be, so it will be 240 by 221 f u into plus 2 into Vr by c minus the expected downlink frequency which is 240 by 221 multiplied by f u. Now, by reducing this expression will be 240 by 221 f u into 2 Vr by c because the 2 Vr is there. So, the radial velocity can be expressed in terms of the Doppler and the uplink frequency or it can be done in terms of downlink frequency and Doppler, only this ratio will change that factor will change.

So, this is a nice expression, and from that we can find out any unknown if the delta f is known I can find out the radial velocity, if radial velocity is known I can find out the expected delta, etcetera, etcetera depends on f u and f d and their ratio. So and of course we have to see that radial velocity is positive or negative depending on which direction the satellite is moving.

So, this is also another part of the range which is called range rate. With this let us complete the discussion on telemetry tracking and command which is say brief description will going to the other sub systems. Let us go to another very important sub system which is power.

(Refer Slide Time: 12:12)



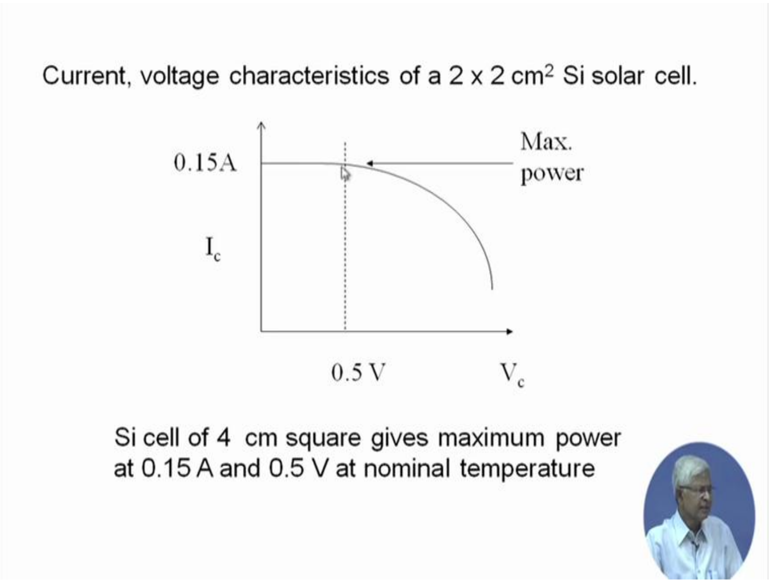
Now, power in case of satellite will have and common satellite typical satellites, will have two types of sources; one is the solar power what we take, another is when sun is not available that is when satellite is under the shadow of earth it is the battery power that you support which will call secondary power, is solar power will charge the battery keep it

So, will try to see how you can generate the solar power and what is a size of the solar panel etcetera? Let us further discuss. The energy which comes or the solar radiation which comes to the earth approximately average it is estimated and calculated and it is when found that it is roughly about on 1370 watt per meter square, it is a typical number it may not be very exact 1370 watt per meter square which is near earth that is the average solar radiation which reaches. But we have to remember the earth is moving around the sun not in exactly circular path it has certain eccentricity. So, sometimes in the year earth is away from the sun, sometimes from in the year earth is nearer to the sun.

So, this radiation will be varying based on the eccentricity, the eccentricity is roughly estimated as 0.89 or 89 percent. So, this also tracker as we considered when goes away from the sun solar radiation which will be reaching the satellite will be smaller. We have to also assume certain things like from sun to the earth surface or earth atmosphere whatever average solar radiation your talking almost it will be almost same to this particular type of satellite which is low earth orbit or medial earth orbit or even geosynchronous orbit. Though from the earth surface it is 36000 kilometer, but if you see the distance from the sun to earth is very very large. So, we can take this number which is reaching the earth satellite as same which is reaching the satellite.

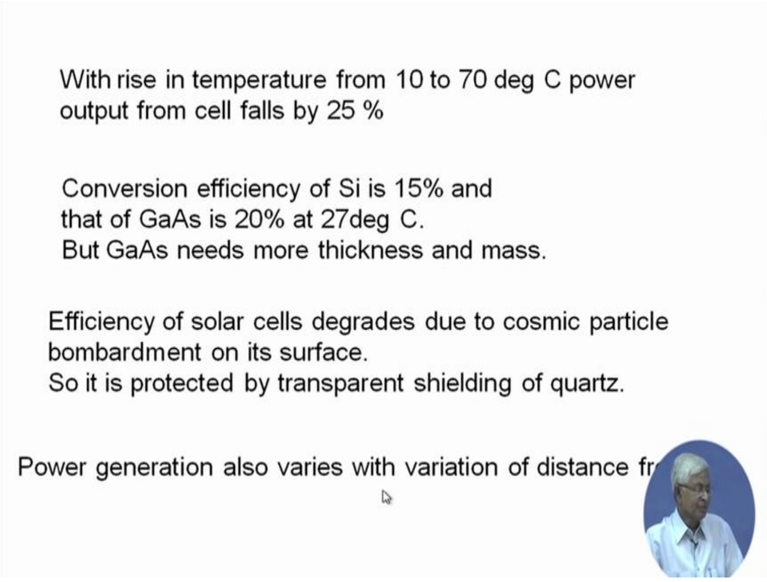
Now, solar cells are commonly at present also it is being used as silicon and or a germanium gallium arsenide, its germanium gallium arsenide and these two will different properties. People have experimented on that.

(Refer Slide Time: 14:46)



Mostly silicon’s are used, let us see the current voltage characteristics of a 2 by 2 centimeter square the 4 centimeter square silicon solar cell. It is roughly it goes like this that initially at very low voltage current is constant and then as the voltage increases the current fall. So, the maximum power can be attained when the voltage is about 0.5 volt, current is about 0.15 ambient these are all typical values. So, we can set the operating point at this place.

(Refer Slide Time: 15:45)

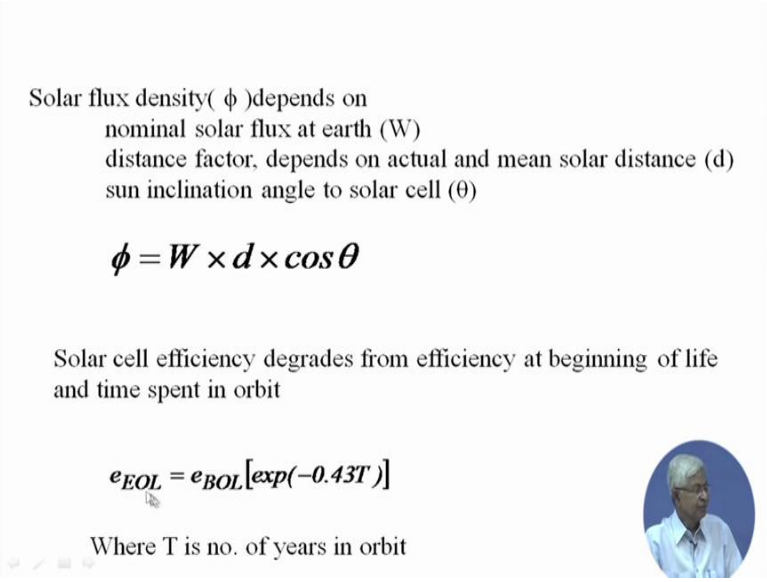


There are other problems that are which temperature variation this power output from the cell falls as the temperature rises at falls and of course solar cells are facing a different temperature at different time when it is away from sun or a certain tilt angel it will face certain different temperatures.

In the conversion efficiency is in silicon is lower gallium arsenide is higher and particular temperature is normal temperature, but then gallium arsenide has more thickness and it has more mass. So therefore, before selecting gallium arsenide like that compromise has to be seen because though it is increasing your full requirement for launching that will be increasing etcetera. So, this is also another consideration for selection.

Now, also one more thing happens that cosmic particles are continuously bombarding in addition to the solar radiation which is on the cell surface, solar cell surface. So, solar sense efficiency reduces and many times it is protected by a quartz shielding. So therefore, it does not get damaged very quickly, but it is over the life it is efficiency decreases then as we mentioned that power generation also varies with the variation of the distance from the sun.

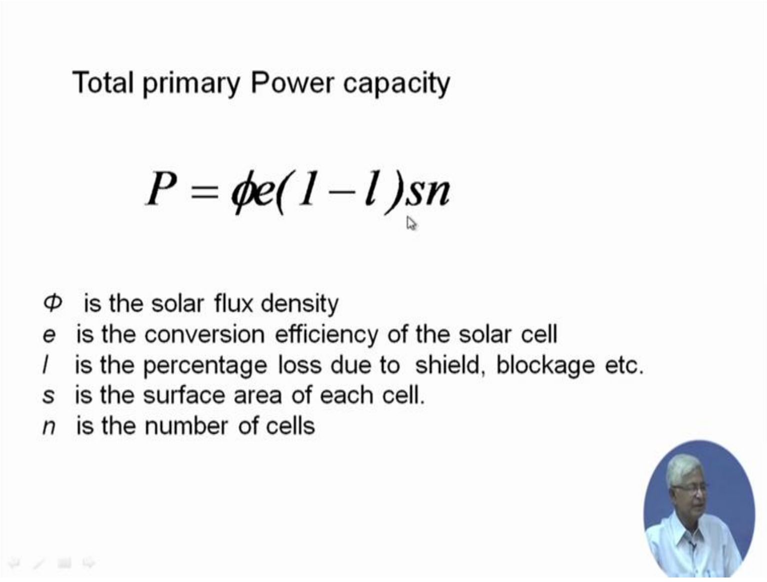
(Refer Slide Time: 16:55)



One more thing that is the solar flux density depends on the nominal solar flux on earth, similar to the satellite around the earth. The distance factor depends on the actual and mean solar distance also at what inclination angle it is falling. The sun is may not be always perpendicular to the solar panel depending on our to arbitrary control etcetera as well our panels also slightly adjusted and depending on the position on the satellite it may have certain degree that is theta which may not be 90 degree always.

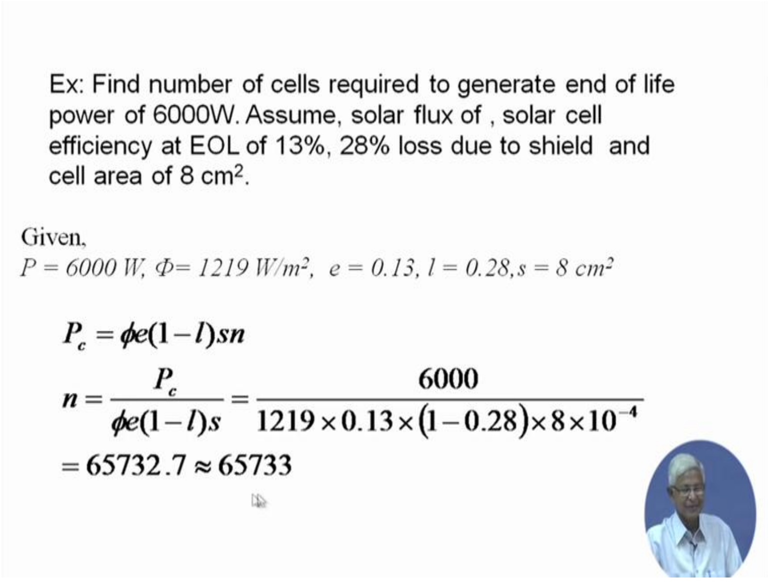
So, this can be expressed in terms of solar flux density depends on the nominal solar flux distance multiplied with the cos of theta. Now one more thing that solar cell efficiency as I said because of various reasons it will degrade from the beginning of life to the end of life and that depends on how much time it is been exposed to the sun and its spending life in the orbit. Therefore, there is another expression it is a model which is efficiency at the end of life EOL is equal to efficiency at beginning of life multiplied by exponential of minus 4.43 of the time number of years it has been in the orbit; minus 0.43 of the number of years it is spent in the orbit, because when it is in the orbit it is facing a different type of environment. So, the end of life or as the time passes it will be reducing.

(Refer Slide Time: 18:42)



So, with all this different factor that total primary power which is coming from the solar cells can be expressed in terms of solar flux density, they conversion efficiency e, then there is certain percentage loss due to that shielding which is done as well as the shuttles shadows that might be falling on to the solution the body of the satellite will or antenna might be creating certain shadow, so there is certain loss which is small l. And then surface area of each cell and of course number of cells. So, when this requirement of the power is known and other factors are known we can cal how many number of cells are required for a particular cell surface area s.

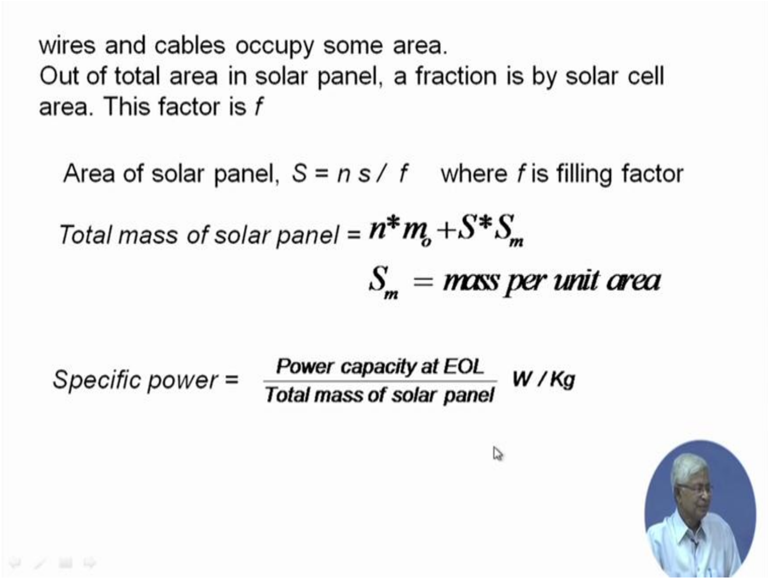
(Refer Slide Time: 19:29)



I just put a very simple type of estimation which you should calculate find the number of cells required to generate the end of life power of 6 kilo watts. Assume that solar flux here the number is missing as in the solar flux is 1219 what per meter square. The solar cell efficiency at the end of life is that in percentage and l which is the shadow that loss due to shield is about or and shadow is 0.28 that is 28 percentage and the cell area is roughly 8 centimeter square.

With this we can put into that same formula and you could do it yourself and you will find that in fractional number with decimal points and obviously the next higher number has to be taken as solar in. So, that power generated will be slightly more than that but it should be an integer number you cannot put a fraction number of a solar cell.

(Refer Slide Time: 20:42)



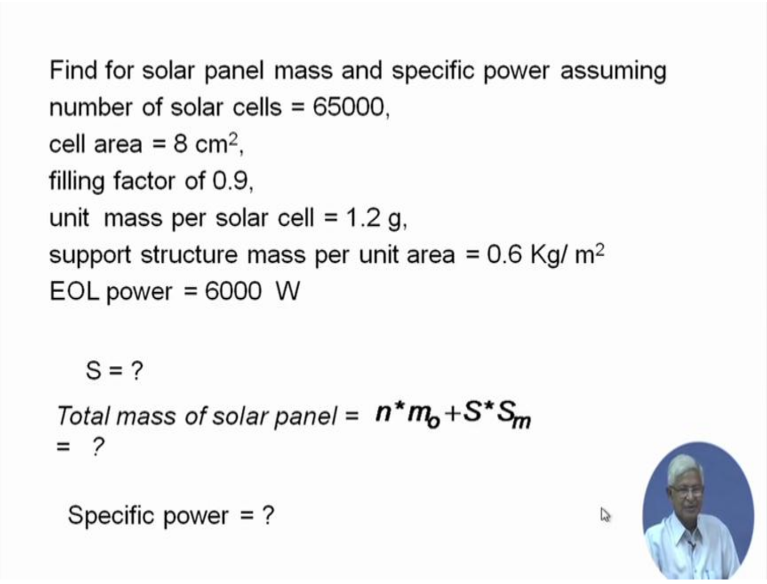
There is certain more things that is when you put the solar cells between the cells the wires will go, so if you try to calculate 40 is the solar panel size that time we have to considered that. So, out of the total area of the solar panel a fraction will be taken by the solar cell so that fraction is called factor the filling factor f.

So, the area of the solar panel will be the each cell surface small s as we have seen in the last expression and n is the number of the solar cells required, so total solar cell area and then divide by the filling factor. That is total solar panel multiplied by the filling factor is n into s other way also it can be expressed. So, we have got the solar panel area.

Now what is a mass? The mass of the solar panel will depend on individual solar cell mass which is small m 0 multiplied by the solar number of cells and then this solar panel area that is s multiplied by mass per unit area of the structure. With this we can get the total mass of the solar panel. Your saying that what we have trying to slowly go it is what are the size of solar panel that is required, what is the mass of the solar panels required. And then really for that mass how much really powered we are getting.

So, that is the quality factor that is a specific power, the term is specific power is power capacity at end of life divided by total mass of the solar panel that that is what your launching, because area is not that of a concern because you on the space you have some I mean enough area to spread your winds but here the specific power will depend on the how much mass your launching. So, the power generated or power remaining at the power generated at and the end of life I should said. So, power capacity at the end of life divide by total mass of the solar panel that is watts per kg, if this is mass is in terms of kg if is in terms of grams etcetera.

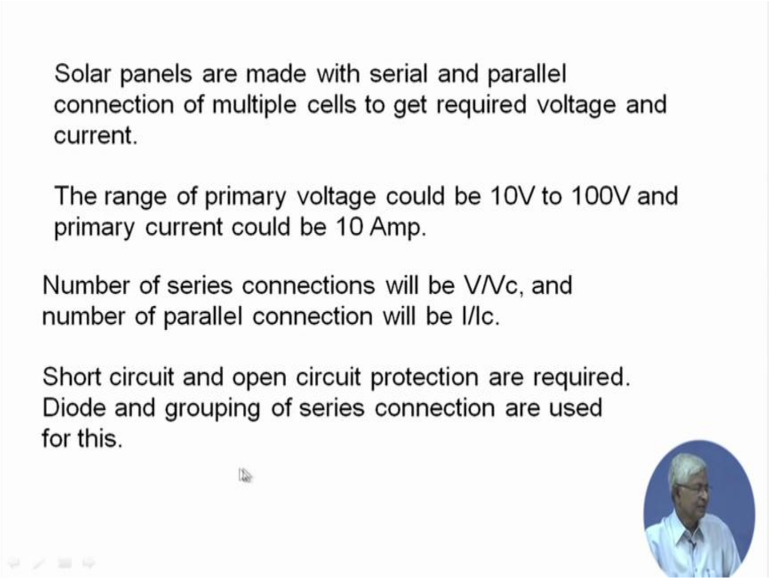
(Refer Slide Time: 22:57)



So, another small sum there find the solar panel mass and specific power assuming number of solar cells 65000 solar cell, area is 8 centimeter square, similar numbers filling factor 0.9, unit mass per solar cell that is 1.2 gram careful this is gram and then support structure is given kg per meter square; careful these two units are slightly different gram and this is kg per meter square. So, per unit area is 0.6 kg per meter square this is in meter square and cell same area is centimeter square, so there is also to worry about the unit.

And in the power requirement is a 6 kilo watt end of life power requirement is 6 kilo watt. So, what is the s? And what is the solar panel mass you can calculate out of s, s is that area and then you can find out the mass of the solar panel by this same formula we have seen earlier, what is that number. And then what is the specific power because the end of life power requirement is given and mass you are calculated. So, you can do is calculation (Refer Time: 24:04).

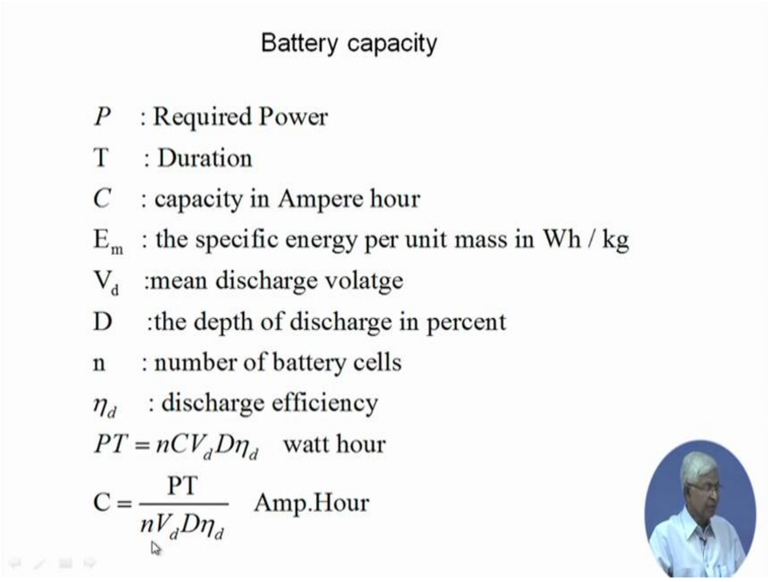
(Refer Slide Time: 24:07)



So, solar panels are made which serial parallel connection, because each of solar cell gives we have seen that it may be fraction of a volt that is 0.5 volt roughly we assume, but in the c electronic circuit you may need 5 volt, 15 volt and then we made it much more current. So therefore, it is serial parallel combinations are done. A requirement may be varying from 10 volt to 100 volt and may be current may be required up to 10 ampere. So, the number of series connection and number of parallel connection can be found out the required voltage divide by voltage per cell v by vc or required current divide by current per cell that is I by Ic. So, number of series parallel connection can be.

But then in addition you have you provide short circuit and open circuit protection. You will be winded in why short circuit protections, of course you will your electronic circuit which the power supply is drivy make it short in so we should have a short circuit protection. Due to many reasons it may get open circuit also some have to open the short circuit protection. And general power supply design is used diode and grouping of series connection are used and do this anything.

(Refer Slide Time: 25:32)

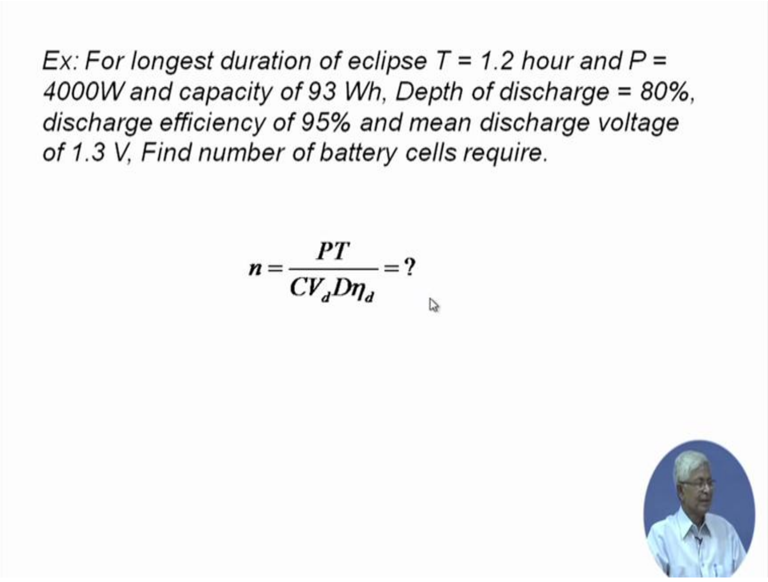


Now, let us go in to the secondary power consideration. There is required battery power let us assume is P, and the duration doing which this required power has to be maintained by the battery is T. And capacity of the battery is in ampere hour is capital C. Specific energy that is it per unit mass is watt hour per kg that is E m. Mean discharge voltage as you draw the current output battery will have certain voltage discharge it will reduce or mean discharge voltage is V d. Capital D is depth of discharge in percent. N is the number of battery cells that is required. And eta d is the discharge efficiency. So, it can be expressed that required power multiplied by the duration on which the power is required the PT that depends on n into C into V d into capital D into eta d that is watt hour.

From that you can find out the capacity of the battery in ampere hour C is equal to PT by nV d Dn d when all other parameters are known we can find out capacity will equivalent is known and required power is known they will be find out the end this.

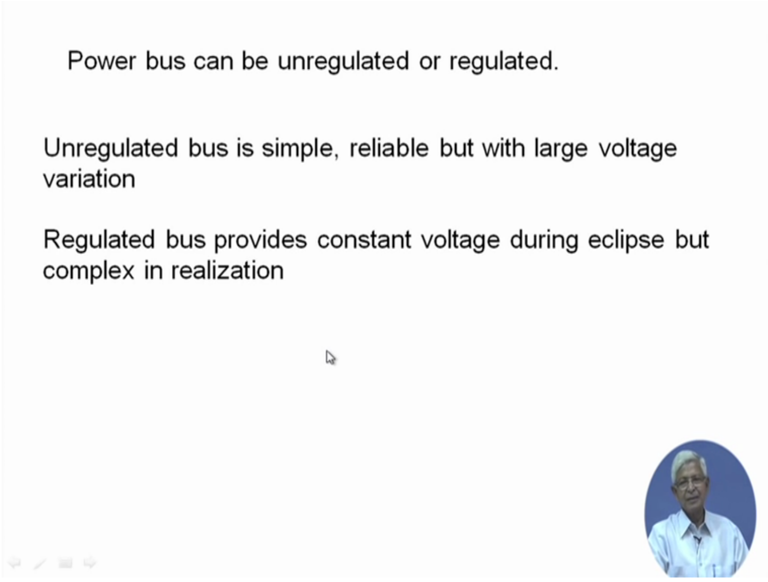
So, you started battery capacity and that can be expressed in terms of the required power and the time duration P and T, and capacity in ampere hour C, specific energy per unit mass is watt hour per kg is E m, mean discharge voltage V d depth of discharge is in percentage is capital D, n d is number of battery cells discharge efficiency eta d. So, PT is equal to nC V d Dn eta d and from that you can find out the capacity required in terms of number of cells.

(Refer Slide Time: 27:39)



So, let us look at a small sum based on the similar expression. There is for longest duration of eclipse we have seen roughly it is T is 1.2 hour during which the battery has to support the transponders, so P is equal to 4 kilo watt, capacity in 93 watt hour, depth of discharge 80 percentage discharge efficiency 95 percentage, mean discharge voltage 1.3 volt. Find the number of battery cells required. You can use that same formula.

(Refer Slide Time: 28:08)



So, power bus can be regulated or unregulated. Unregulated buses are simple and reliable, but large voltage variations will be there on the bus. And regulated bus provides the constant voltage during eclipse, but complex in realization and each circuit will draw different types of current generate some spike spurious (Refer Time: 28:26) on the power supply. So, though regulated bus sometimes is zero and each sub system use their own regulator.

With this we stop at the power subsystem, we will continue further with other subsystem.

Thank you.