Satellite Communication Systems
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Lecture – 10
Space Segment – 5

We continue our discussion. We were talking about the payload and we discussed about the transparent payload which is another term people use which is called bent pipe in the sky. So, it is bent pipe transponder or bend pipe you know, but then there are certain requirements through for that people use much more complex transponders which is called onboard repeaters or onboard switching repeaters.

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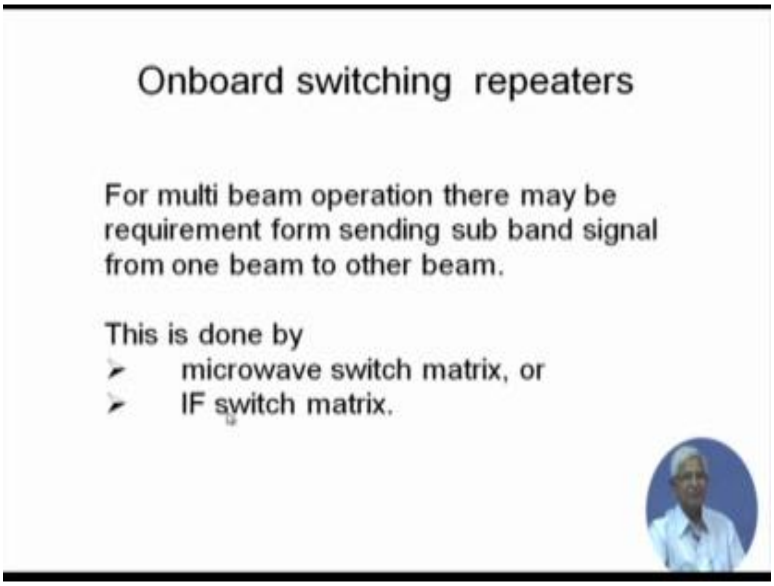

Let us see from multi beam operation, different spot beams are used. We will discuss about that later. There may be requirement from sending the sub band signal from one beam to another beam. This is done by the microwave switching matrix onboard or i f switching matrix when we convert into intermediate frequency and matrix, it can be regenerative and also, the signal can be demodulated and regenerated.

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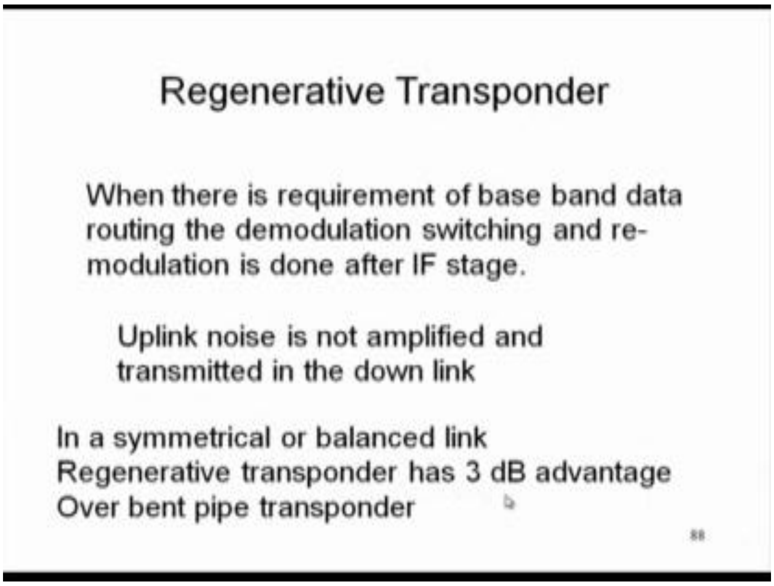

So, it is called regenerative transponder. So, that is another form when there is a requirement for the base band data has to be extracted and then, routing is done through the switching. So, after demodulation switching is done and remodulation is done after the IF stage. So, this is much more complex in that case advantage is uplink noise is not directly amplified because you have come down to the base band and then going up from the base band. So, the noise is not transferred to the downlink is one of the advantage. So, in the symmetrical or balanced link when uplink and downlink are symmetrical link, we will discuss about that later. Regenerative transponder has certain 3 dB advantage over the bent pipe transponder. We will discuss that one much later.

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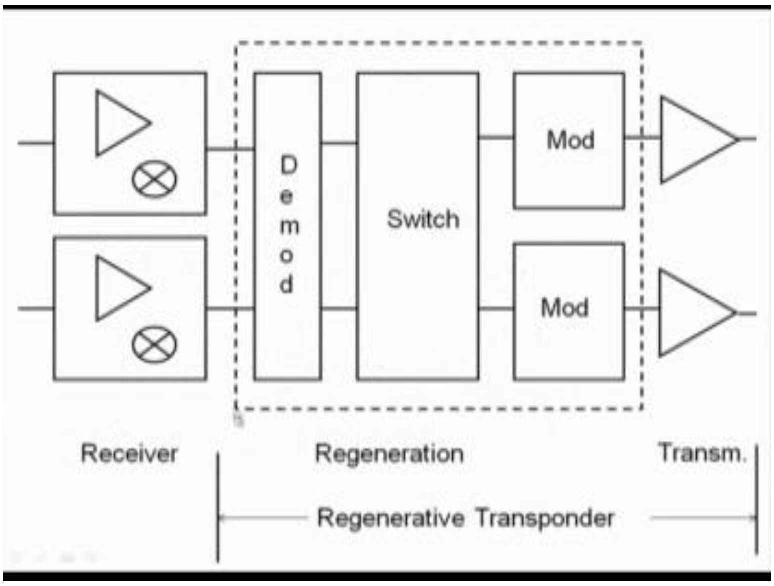

A very short block diagram we will be discuss in detail of that, but short block diagram is this is the receiver very small symbol put this block is amplifier and the mixer means system conversion together. So, from different beams, it is coming and then, they are put into a demodulation. I said a demod actually there are many demods here and then, after that there is the processing or routing or switching is done at that digital level, this bent level and then it goes into the modulation and then up conversion and then amplification.

So, this plot after the receiver is called regenerative transponder which includes in bent transponder. That is there is the omox, demox and the amplifier also the demodulation remodulation along with the switch which is regeneration put together is called regenerated transponder. Now, with this we go into one of another important sub system which is their onboard as well as which comes on the ground is antenna. We will discuss the antenna briefly now and more details of the antenna will discuss later.

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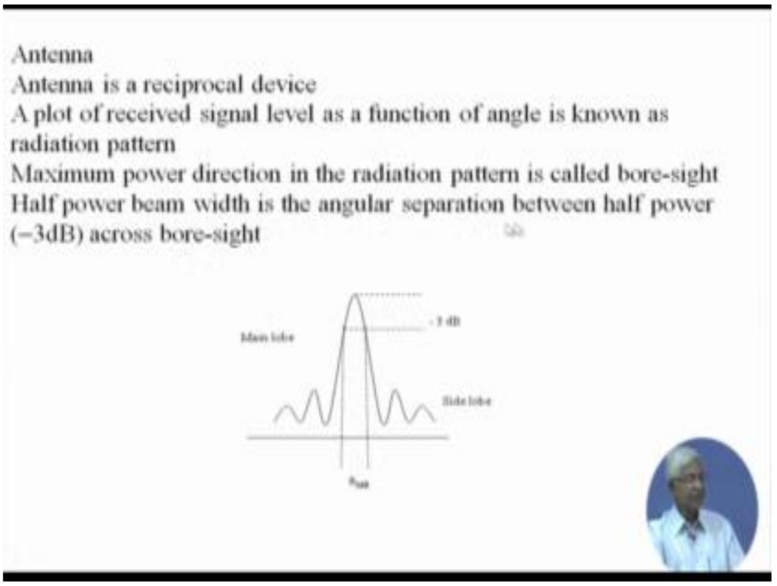

As we go through this course, antenna is an important thing that is we are trying to take at certain advantage from the antenna in particularly in satellite communication, antenna is required for wireless communication is nothing, but it is reciprocal device is same. Antenna can be used for transmission as well as for reception. Now, I will try to plot antenna as directive. So, you can think of a coordinate system which is theta pi r coordinate r theta phi coordinate system. So, receive signal level is a function of the angle theta is known as radiation pattern or transmit signal level as I said it is reciprocal device. So, transmit or received signal is immaterial in a linear scale. It can be plotted like that in x direction. If it is the theta angle or phi angle here, I have shown theta and then the power is at zero degree is the maximum power.

It is assumed and then as we increase the theta either in positive direction or in the negative direction, the power falls and it fix, again it falls, again fix again like that. So, the main peak is called the main lobe and the small peaks are called side lobes and from the maximum power when the power falls at a particular angle of theta when the power is half of that maximum power its minus 3 dB point. So, these angles is called theta 3 dB as engineering, but approximation we will try to always use this theta 3 dB which is half power from the maximum and this maximum power direction is called bore sight. The maximum power direction of the radiation pattern is called bore sight. This radiation pattern can be drawn in theta phi coordinate also is a linear.

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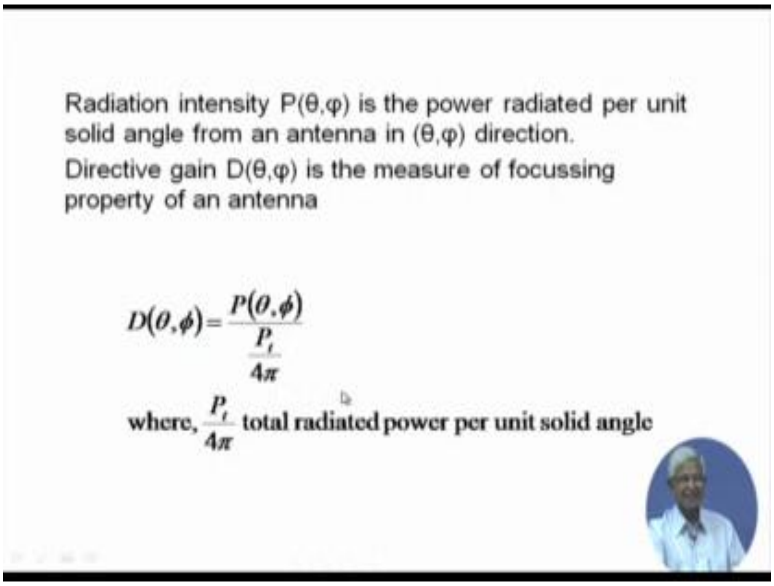

Half power beam width is angular separation between half-power across the bore sight. Now, let us try to see how much we are focusing. So, that can be expressed in by term radiation intensity. That is nothing, but a power radiated per unit solid angle in theta phi direction. Let us call p theta phi from an antenna in theta phi direction per unit solid angle. So, therefore we can define a term called directive gain capital D which is also theta phi direction. Directive gain is the measure of the focusing property of the side which is p theta phi and transmit power by 4 pi. This P t by transmit power by 4 pi is the total radiated power per unit solid angle. So, the ratio of p theta phi by p t by 4 pi that is the directive gain, but this is with the radiated power we have sending power amplifier output which is going to the antenna which is the input power to the antenna. So, therefore this has to be translated into the input power.

Now, the power which is going to the satellite antenna as an input, many not be fully radiated because there may be some loss in antenna system. So, there is certain efficiency.

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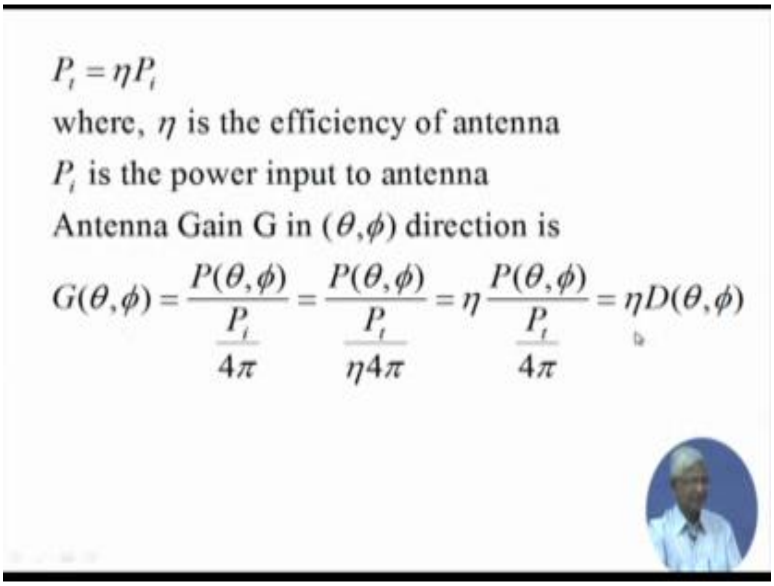

So, that transmitted power is some factor of the input power which is we call efficiency. That eta in this case is the efficiency of the antenna. So, input power is a power input to the antenna and then, we can define another term antenna gain g in again theta phi direction is ratio of p theta phi by p input by 4 pi and p input by 4 pi is p t by eta 4 pi. So, this whole ratio is p theta phi divide by p t by eta 4 pi. Now, this eta can be taken up. So, it is p theta phi by p t by 4 pi which is nothing, but directive gain d theta phi. So, g which is we call antenna gain in theta phi direction is the efficiency time eta times the directive gain D, D theta phi.

So, this efficiency determines how much power which is going as input to the antenna is really getting radiated. So, efficiency should be as high as possible it depends on antenna design.

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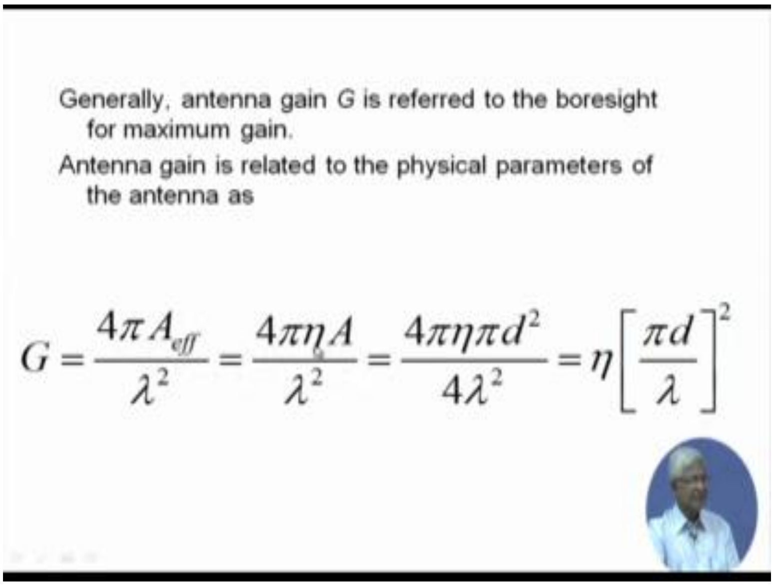

Now, this g again is related to some physical parameters. Generally this antenna gain g is referred to the both side. We won't go for g theta phi detail. So, with g is generally taken as bore side the maximum gain. So, it is actually g max. So, g is 4 pi of effective aperture of the antenna by lambda square. This effective aperture is eta times the physical aperture because there are certain losses in the aperture. Aperture may not have exactly the way it is supposed to transmit. So, 4 pi eta a by lambda square and as we know is phi d square by 4. So, the g is expressed in terms of eta into 4 into pi d by lambda whole square. This 4 get cancelled pi d by lambda whole square.

Now, this also can be related to the theta 3 dB which is nothing, but beam width the half power beam width theta 3 dB is expressed in terms of wavelength.

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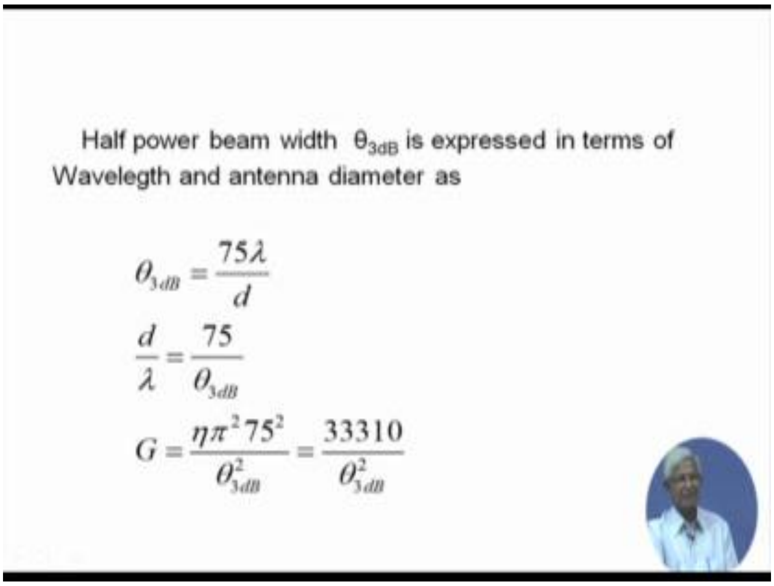

Antenna diameter it depends on the radiation to the antenna and generally in case of satellite antenna, we use because higher focusing abilities is required. We use a parabolic reflector. So, as I give you last time example at one near bank ATM, you will find certain VSAT's. The reflector is parabolic. You might have seen that the directive home services through which you receive TV that is on the roof top, many people are put. That is also a reflected parabolic reflector and the cable operators we also use parabolic reflectors for satellite normally on satellite also we have parabolic reflectors that picture of satellites what I shown you earlier. So, the diameter of that parabola the phase of the parabola is called is here small d and the wavelength on which is operating is lambda and depending on the radiation pattern of the primary feed to the reflector. This term, this number 75 is appearing.

So, theta 3 dB is 75 lambda by d this 75 is just a typical number. Some of the books say it is 72, some people take 70. It is just approximate number. So, here we have taken 75 theta 3 dB 75 lambda by d. Other way we can say d by lambda is 75 by theta 3 dB. Why we say d by lambda because previous expression we have seen gain in terms of d by lambda. So, the gain then can be expressed as eta times pi square 75 square by theta 3 dB square. This d by lambda is replaced there by 75 by theta 3 dB and if we take efficiency eta 60 percent which is generally true if you put this number, approximately this number comes as 33, 310. Some people take it as 33000 and some people take it as 33,300. You can go to very near 33309 point something. So, there is all thumb rules for calculation.

So, gain is related to a number by theta 3 dB square. So, theta 3 dB and gain can be found out or other one if it is known.

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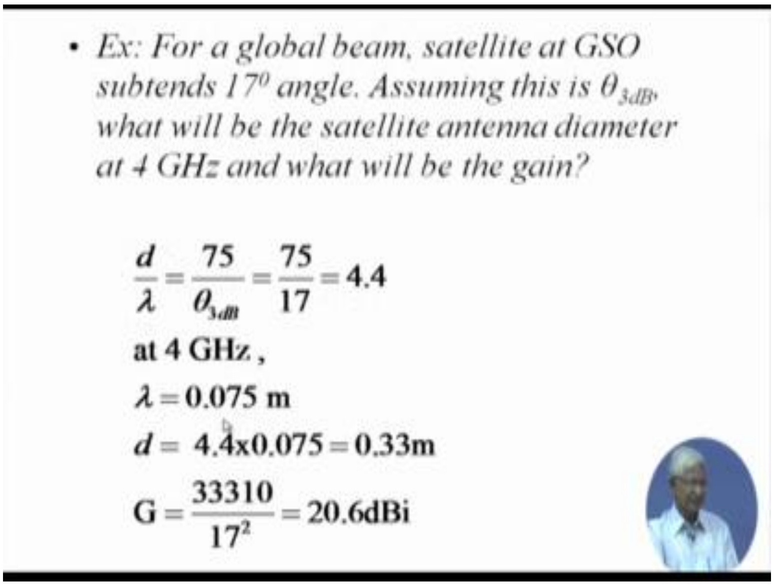

Let us see for a quick calculation a global beam, the satellite at GSO subtends 17 degree angle just recollect in out orbit discussion is 17.4 or some on other angle we have calculated almost 17 degree angle global beam assuming theta that is a theta 3 dB of the satellite. So, what should be the satellite antenna gain and it is a diameter at 4 Giga because lambda is coming at 4 Giga hertz. What should be its diameter and the gain? Easy calculation is d by lambda. First you calculate that is 75 by theta 3 dB 75 by theta 3 dB is 17 degree. So, it is d by lambda ratio is 4.4. So, at 4 gigahertz, lambda is roughly let take 0.75 meter. So, d is 4.4 multiplied by 0.075 comes to 0.33 meter or 33 centimetre. A4 size paper and corresponding gain assuming that thumb rule 33,310 by 17 square theta 3 dB square is equal to in terms of dB, when you calculate it is 20.6 dB. I have put dB i, dB with respect to isotropic antenna.

When we discuss about the antenna detail, we will come across once right now you take this as simple dB. So, gain max will be 20.6 dB and the diameter of the antenna is less than meter. So, for that is for global beam for 17 degree angle.

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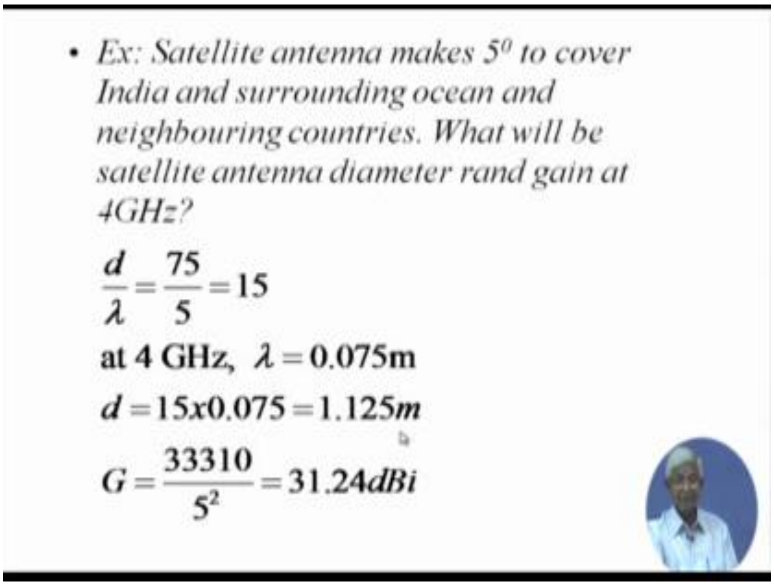

Now, let us see what will happen for smaller angle which is 5 degree which covers roughly from geostationary satellite roughly Indian land mass to cover India and surrounding ocean, neighbouring countries. What will be the satellite antenna diameter and gain? You just instead of 17, you put 5. So, you get d by lambda is 75 by 5 is 15 at 4 gigahertz, lambda is 0.75, d is 1.125 meter. So, 0.33 needed to it as become 1.125 meter and gain is increased to 31.24 dB. So, that is just roughly to show you some thumb rules of the antenna calculation.

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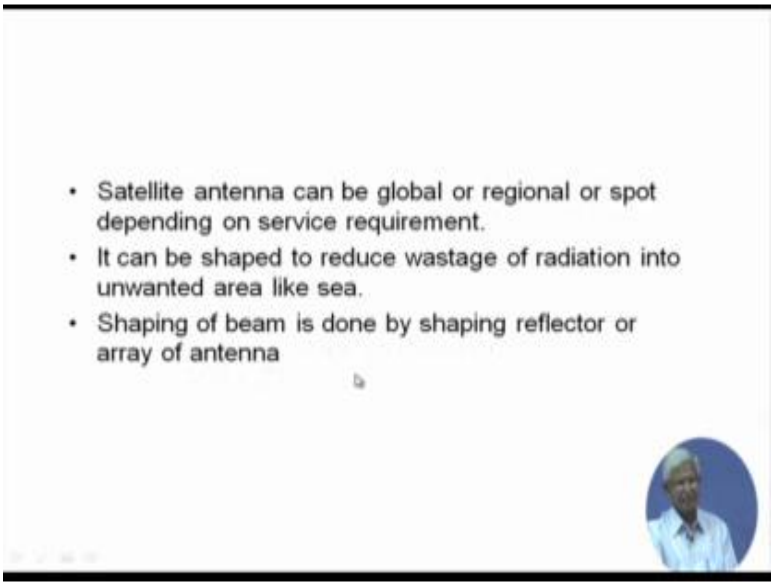

So, satellite antenna can be global regional or much smaller which is spot beams on the services requirement. It can be shaped, it need not be always circular or electrical on the ground may be shaped in different shape. So, that wastage the radiation non-service area like sea and other places can be referred and shaping the beam can be done by reflector shaping and various techniques array, array antenna and various techniques are there.

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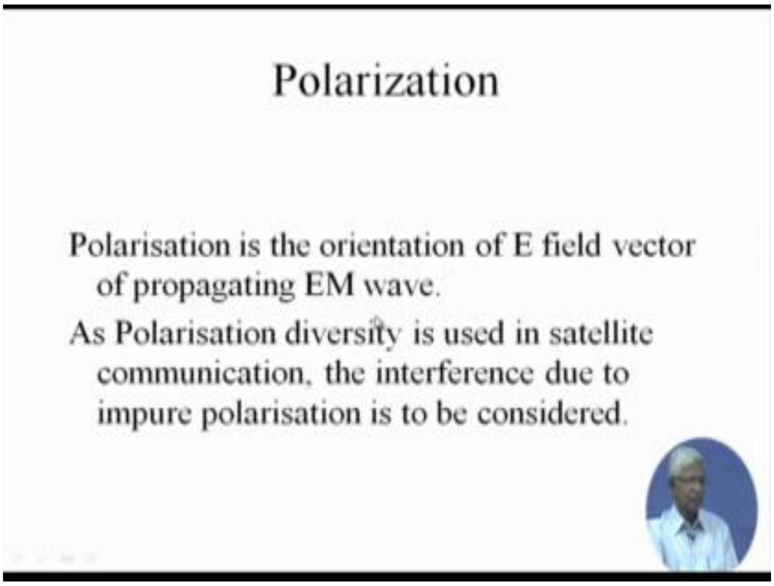

Now, one of the important parts of the antenna is polarisation. Polarisation is orientation of the electric vector field of the propagating electromagnetic wave. The polarisation diversity sometime used in the satellite communication we have seen for isolation. I said polarisation has to be used. Polarisation diversity we have to reduce the interference for to impure polarisation if it is to be considered.

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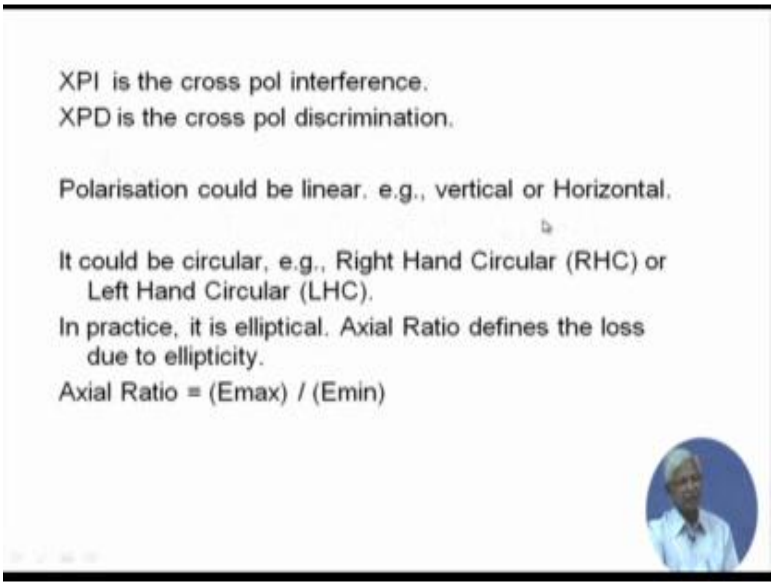

Now, that can be expressed in terms of cross pol interference. The term is XPI and cross pol discrimination XPD polarisation could be linear if the electric field is linear as vertical or horizontal with respect to the antenna from where it is being transmitted and it could be circular also in the right hand circular side or left hand circular side LHC or RHC and this axial ratio is the ratio of electro vector maximum to the electro vector minimum and for circular, it is seen for ellipse. It may be different.

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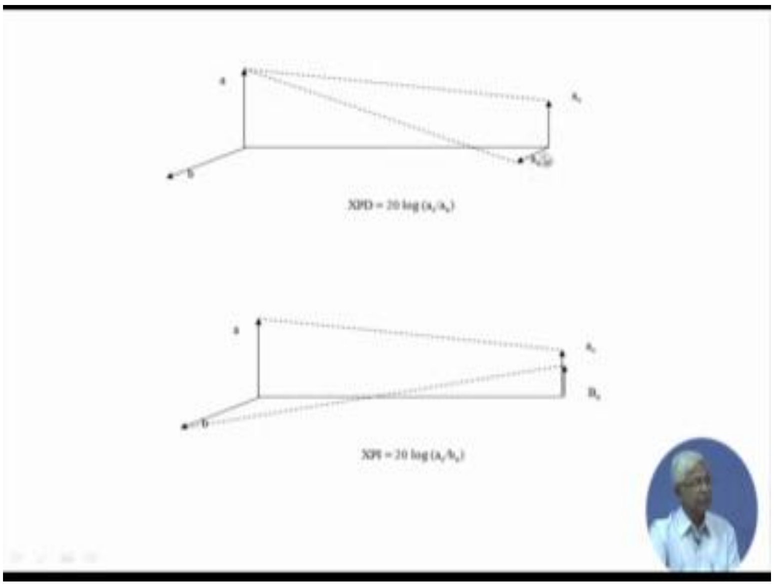

So, it can be 3 dB to understand what XPIs. Let us see there is an electric field which is transmitted, a vector is vertical and horizontal vector v is transmitted. Now, at the receiver because of some impurity, this vector may have a component of x in the x component falling and co-polar component that is the vertical. So, if there is a x component coming that is cross pol component coming over the co pol, the cross pol discrimination is defined as 20 log a co pol by a cross pol a c by a x is 20 log in dB and cross pol interference is 20 log a c by b x and the b is transmitting its component cross pol component is b x. So, actually cross pol XPI gives us how much interference is occurring. So, for orthogonal polarisation with good pure antenna design in transmit and receive side, this should be XPI should be as high as possible. That means, b x should be as low as possible. Ideally it should be 0. This should have advantage and sometimes it is taken.

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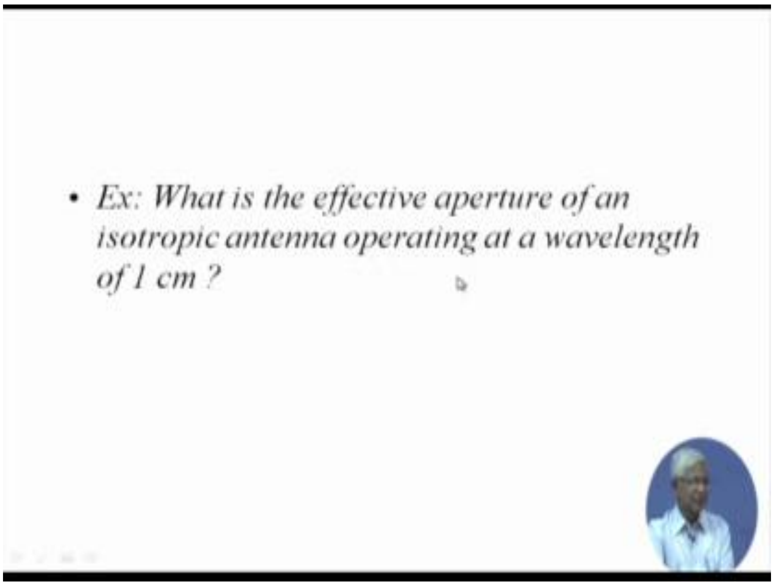

Some questions I am putting you try to find, put your answer what is the effective aperture of an isotropic antenna operating at a wavelength of 1 centimetre? You try to use the formula.

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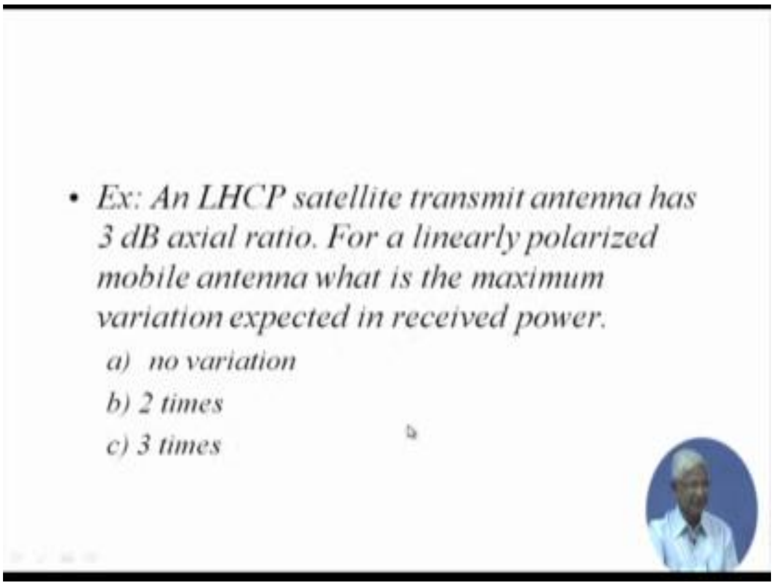

An LHCP satellite transmit antenna has 3 dB axial ratio for a linearly polarized mobile antenna. That means, the transmit antenna is LHCP and receive antenna is linearly polarized antenna that is circular polarized transmission and linearly polarized reception. So, what is the maximum variation expected in the received power. No variation, 2 times variation or 3 times variation. Find out the answer. So, with this we close the antenna chapter.

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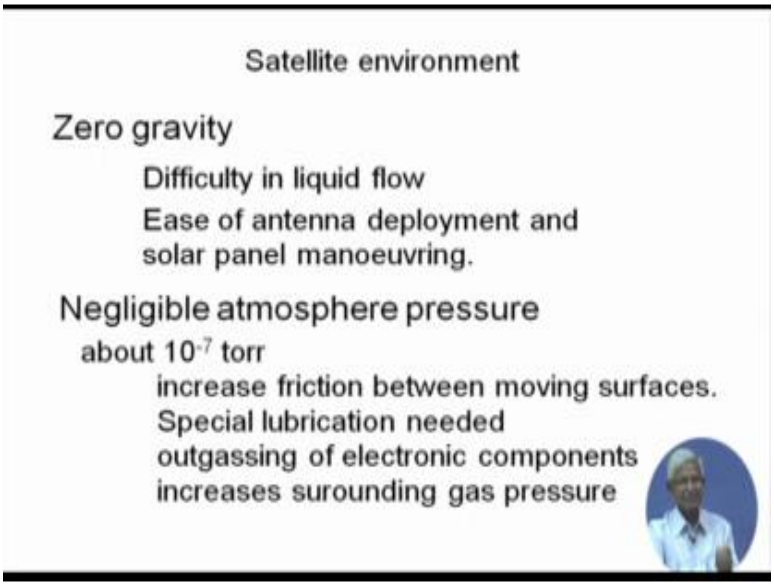

Let us go into the environment on with the satellites are operating satellite environment. Couple of things occur. There it is a gravity is very low zero gravity. So, there is difficulty in the liquid flow. Whatever fluid is there will be certain difficulty, but there is certain ease of antenna development. There is no additional force acting on it or solar panel manoeuvring. There is no atmosphere pressure. We should negligible atmospheric pressure of the order of 10 to the power minus 7 torr. So, that increase the friction between the moving surfaces and special lubrication is needed for that outgassing of electronic components increase surrounding gas pressure out. Gassing means because the vacuum is there, so some gas forms comes out of the electronic component that will increase the gas pressure. So, a negligible atmospheric pressure may be reduced little or increases the atmospheric pressure or global pressure environmental pressure is increased.

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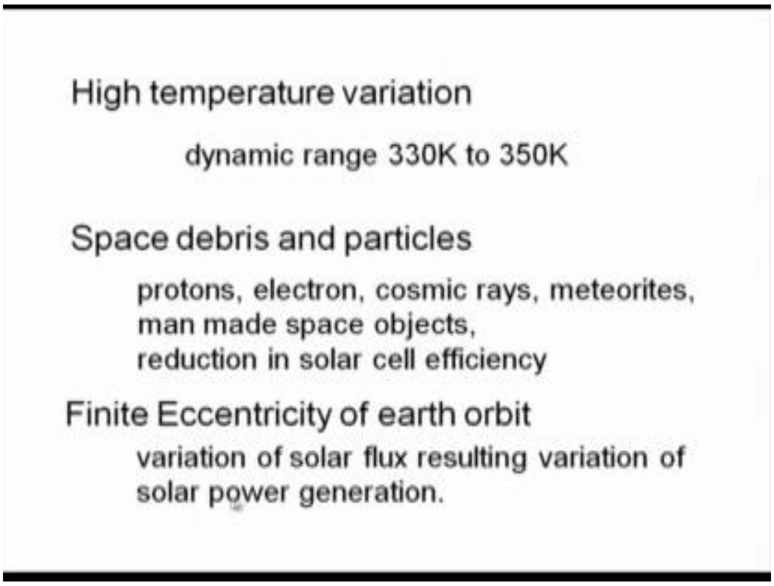

There is a high temperature variation you have seen in thermal design. That is a dynamic range is get large space debris and particles that might be occurring on the satellite body, protons, electron, cosmic rays, meteorites, man made space objects, reduction in solar cells, finite eccentricity of the earth surface, earth orbit. There is a variation of solar flux resulting variation of solar power generation. This we have seen already.

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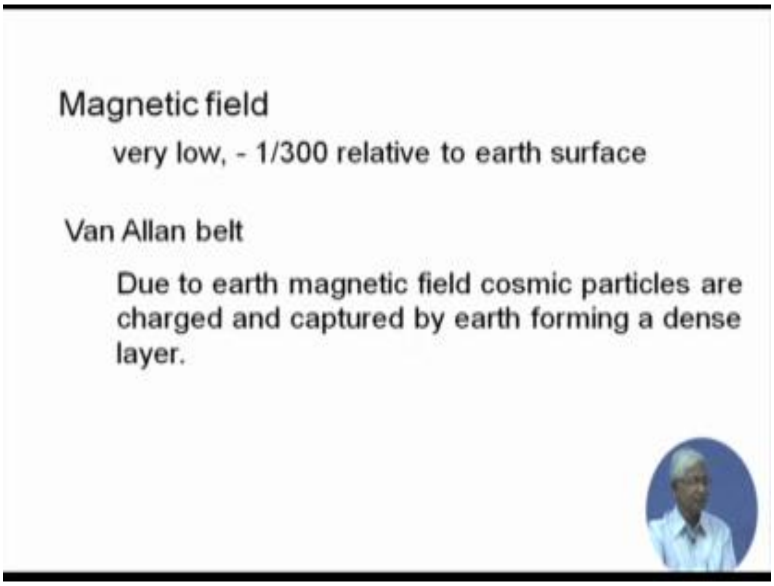

There is a magnetic field. Earth magnetic field is very small. There is almost 1 by 300 relative on the earth surface. So, it does not have much effect. There is a Van Allan belt which is cosmic particles, charged particles move around the earth and they are forming a dense layer. So, that can create problem in the electronic device which is passing through this belt. This belt is almost from the surface of around 20,000 kilometres among the surfaces of the earth. So, the satellite which is passing through this belt has to be protected properly.

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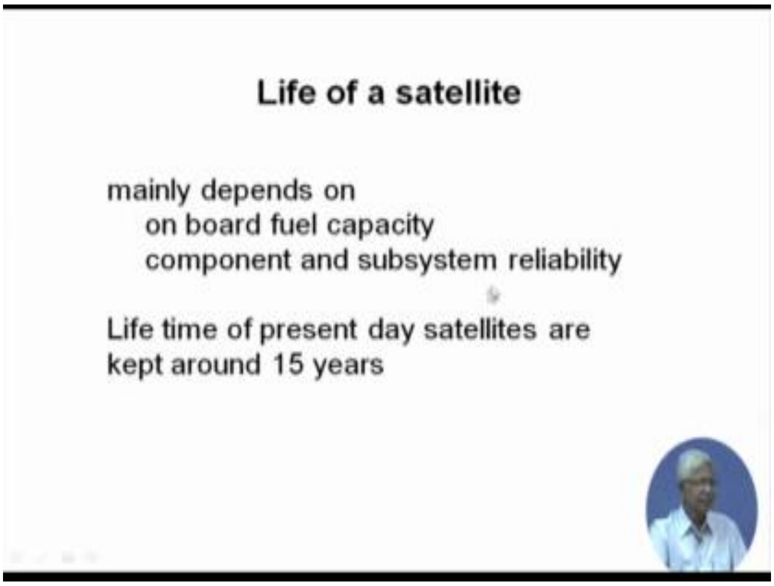

So, life of the satellite mainly depends on the onboard fuel capacity and the failure of the component and subsystem which depends on the reliability. Life time is presently kept as 15 years. Its onboard fuel capacity part we have already discussed. When the fuel is much less, then it is deorbited. So, how much fuel is left that depends on roughly its 15 years to some satellites around. So, 20 years satellite, some satellites are 7 years to 10 years, but let us concentrate more on this subsystem reliability or component reliability.

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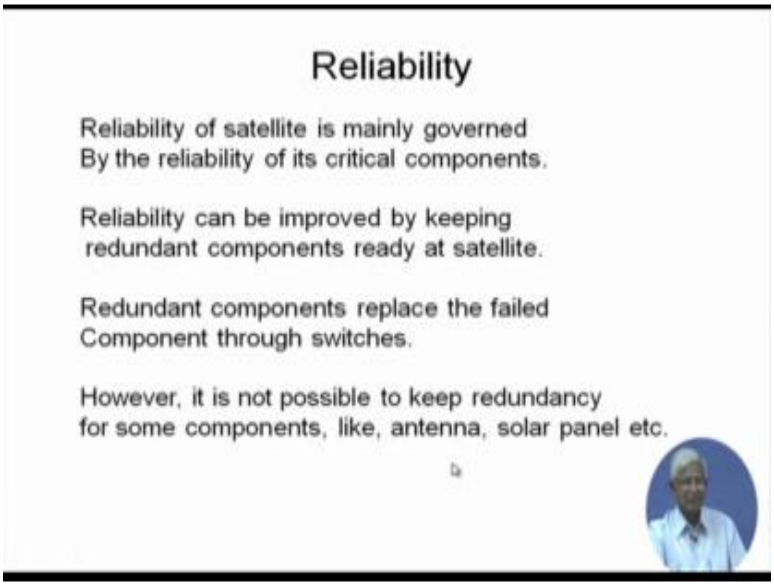

Reliability of the satellite is mainly governed by the reliability of the critical components. Reliability can be improved by keeping the redundant components ready at the satellite. So, you can switch. Redundant components replace the failed component through the switches. So, the path is changed and however, it is not always possible to keep redundancy for all the subsystem like antenna, like solar panel. This cannot be having redundant too much of weight you will be carrying unnecessarily.

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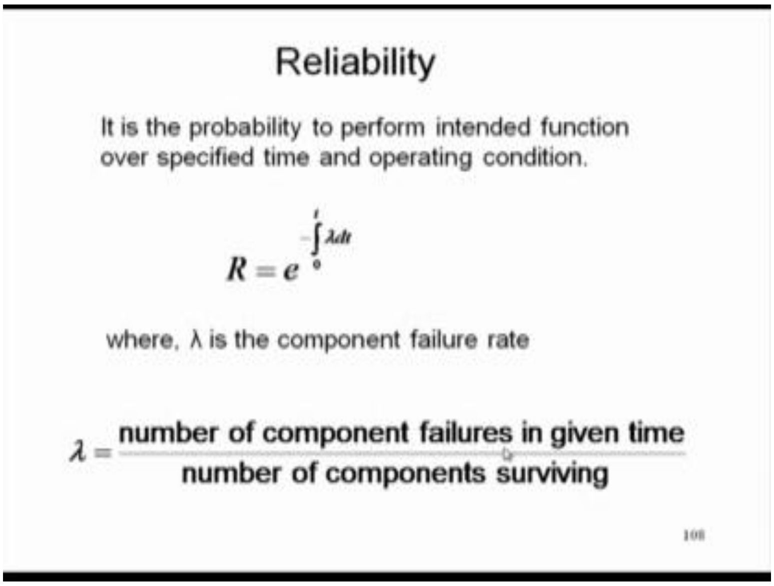

So, we will try to see how we do the reliability engineering. Reliability by definition is a probability performs intended function over specified time and operating condition probability to perform over the specified time and over the operating condition. So, reliability is defined in as exponential of the component failure rate into time over the time that is minus integration of zero to t lambda d t and lambda is number of components failure in given time by number of components that is surviving. That is a failure rate.

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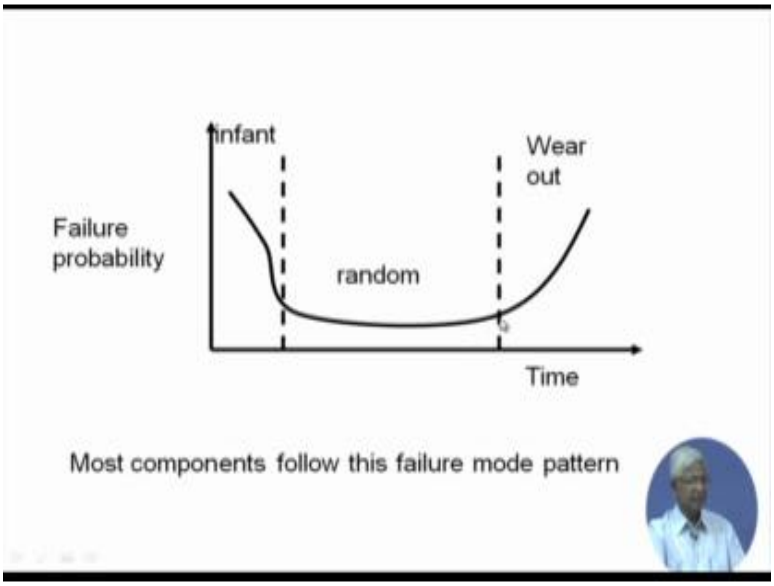

Generally for all components whether it is space are round, it follows a life time circle where initially it fails. Failure probability is quite high during the life time longer period. The probability is random failure and then, there time comes which it wears out is true for the human life and life on the earth everything it is true like this the most components follows these failure pattern. You will try to operate them in this region where it is random failure.

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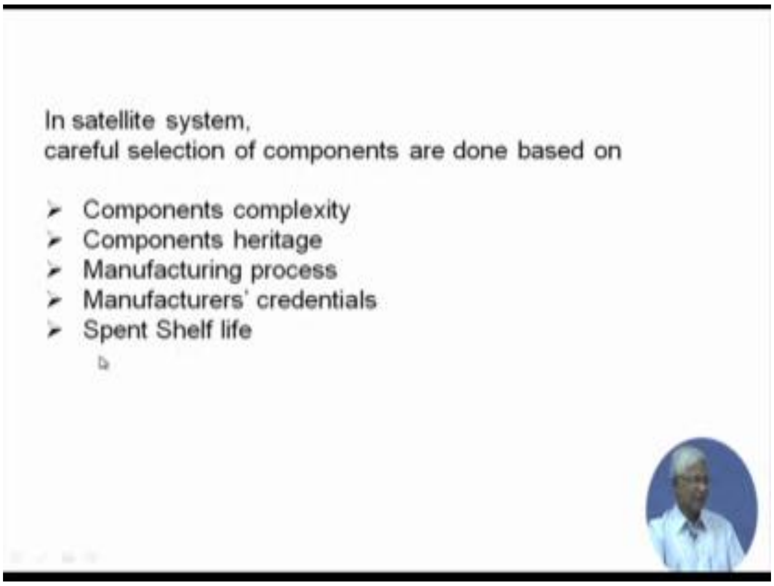

In satellite system careful selection of the components are done based on the components complexity, its heritage where and how it is used, how it perform, its manufacturing process, its manufacture certification that is its credentials spent life in the shelf.

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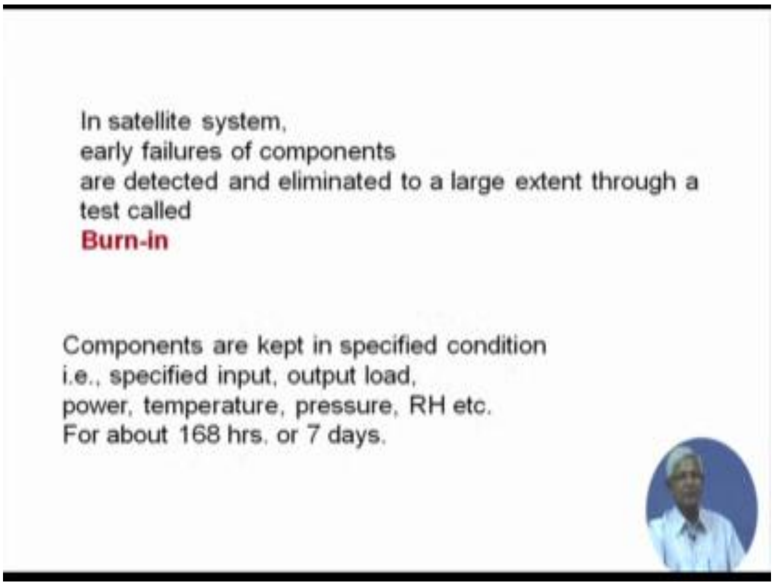

Then in the satellite system, the initial part of the failure of the component is tested and it intentionally those who are supposed to fail, let them fail by a test called burn in. That means you keep it on for 168 hours or roughly about 7 days with a specified input output load power temperature pressure relative ability etcetera with all this specified condition you continuous keep it on for 7 days. So, if it supposed to fail in the infant condition, it will fail. Those component subsystem pass this, they are taken for this satellite fabrication. The main aim is really eliminate the random failure during this operating life time.

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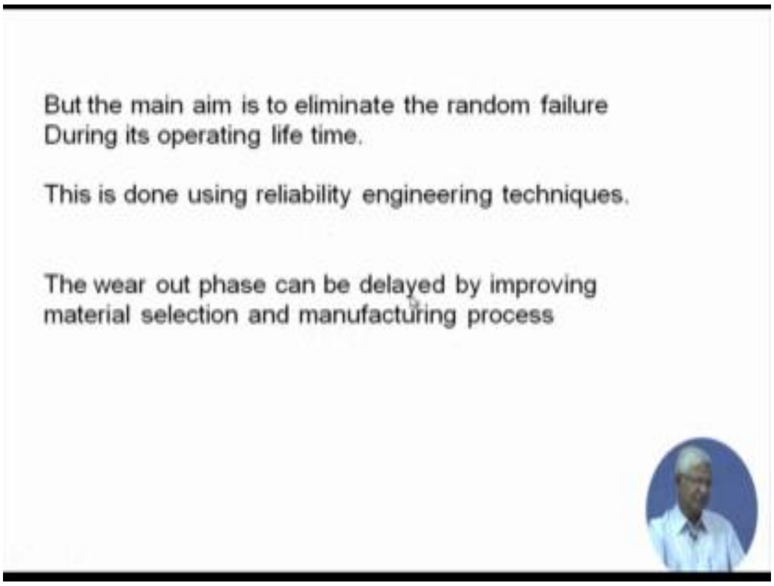

So, that is done by reliability engineering techniques. The wear out phase can be delayed by improving material selection and manufacturing process. So, let us try to calculate what should be the improvement in the reliability engineering. How can you do it? So, we have seen this r is equal to exponential to the power minus integration of zero to t lambda d t assuming constant failure rate over time.

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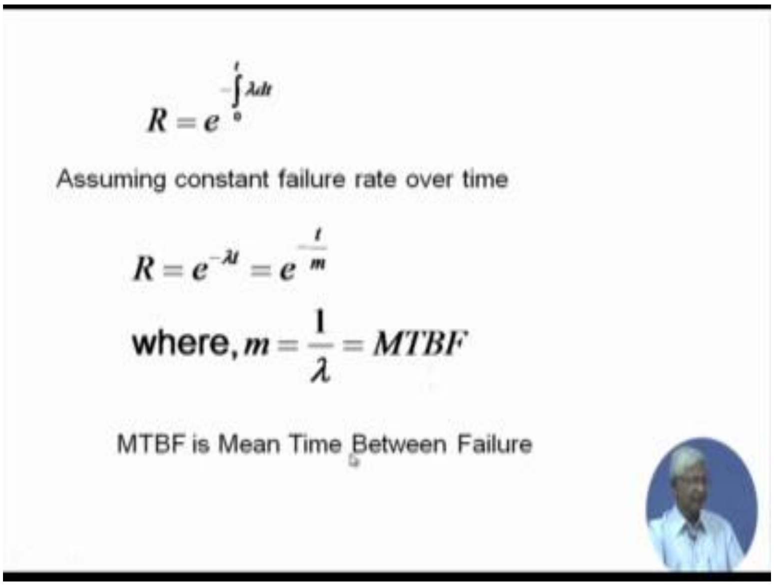

So, it can be e to the power minus lambda t which is e to the power minus t by m lambda is 1 by m which is MTBF m is equal to 1 by lambda. MTBF mean time between failures.

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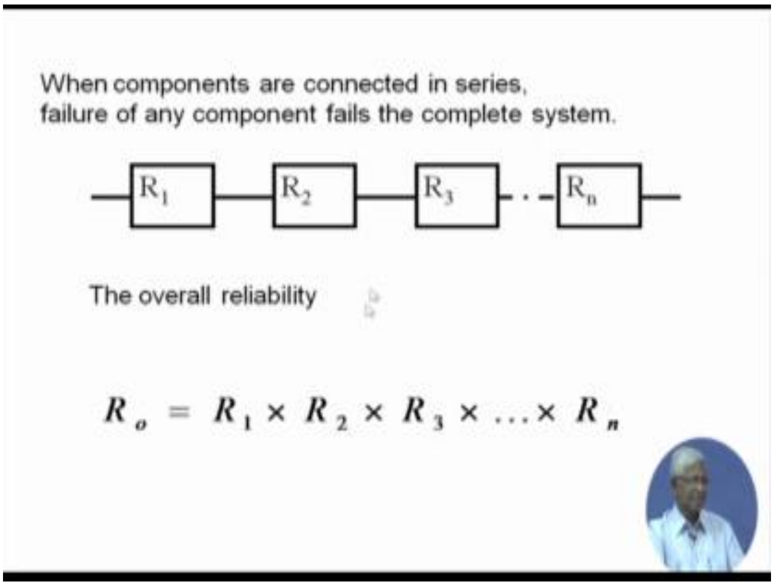

MTBF is mean time between failures when the components are connected in series failure. So, the component any failure of any one of the component fails a complete system. So, the total reliability is overall reliability R0 can be multiplication of R1, R2, R3 up to R n and these r values vary from 0 to 1 is fraction.

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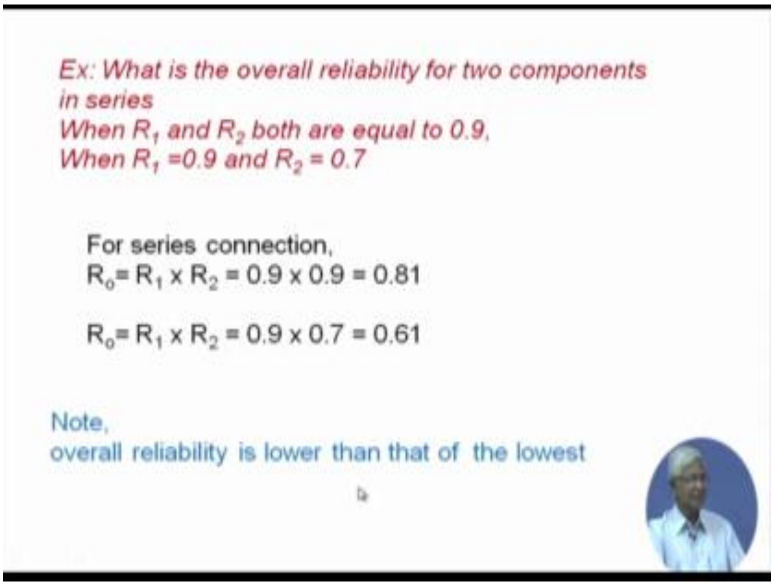

Let us see the numbers. What is a reliability of two components in series? When R1 and R2 both are 0.9 and when R1 is 0.9 and R2 is 0.7, multiply them over all reliability when they both are 0.9, it is 0.81. So, it is less than the individual reliability when it is 0.9 and 0.7, it is 0.61. It is lower than the lowest one. So, over all reliability is lower than the lowest.

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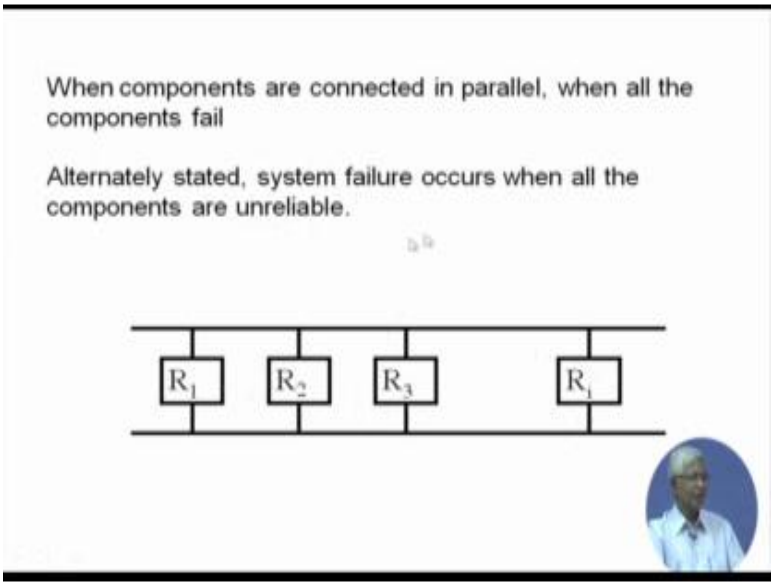

When they are connected in parallel, when all the components fail, then only there is a failure. So, therefore, you can say the system failure occurs when all the components are unreliable.

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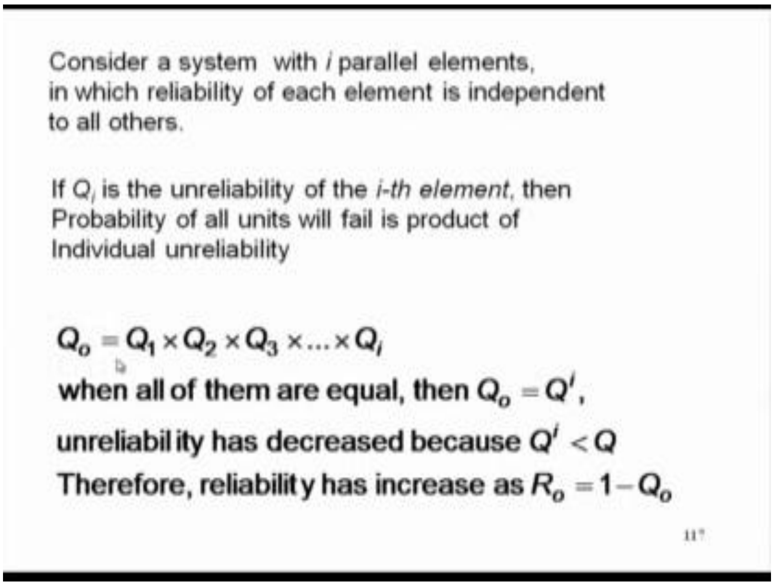

That can be calculated consider a system with i number of parallel elements in which reliability of each component is independent to all others. If Q i instead of R, let us term Q i is unreliability of the ith component, then the probability of all units will fail is a product of Q's that is over all unreliability. Q0 is Q1, Q2, Q3 up to Qi or when all of them are equal, the overall reliability Q0 is Q to the power i and unreliability has decreased because Q to the power i. Q is since R is less than 1, Q is also then 1. Q to the power i is less than Q, therefore the reliability is over all is R0 is equal to 1 minus Q0.

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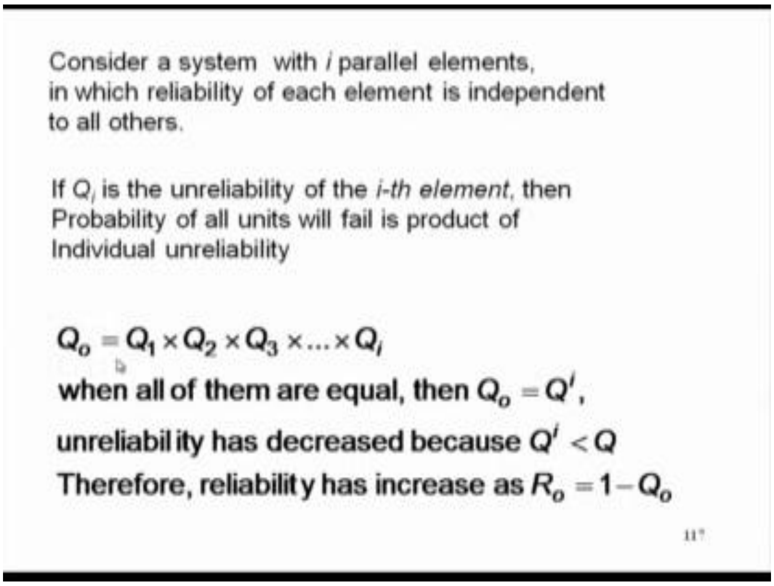

Over all reliability can be derived from individual elements of reliability like this that is Q0 is multiplication of Q1 to Q i and when all of them are equal, Q0 is equal to Q to the power i. R is 1 minus Q. So, R0 is 1 minus Q0. So, 1 minus Q to the power i is 1 minus 1 minus R to the power i. This way you can calculate if the reliability of individual numbers is known overall reliability. When they are parallelly connected can be found from R0 is equal to 1 minus 1 minus R to the power i.

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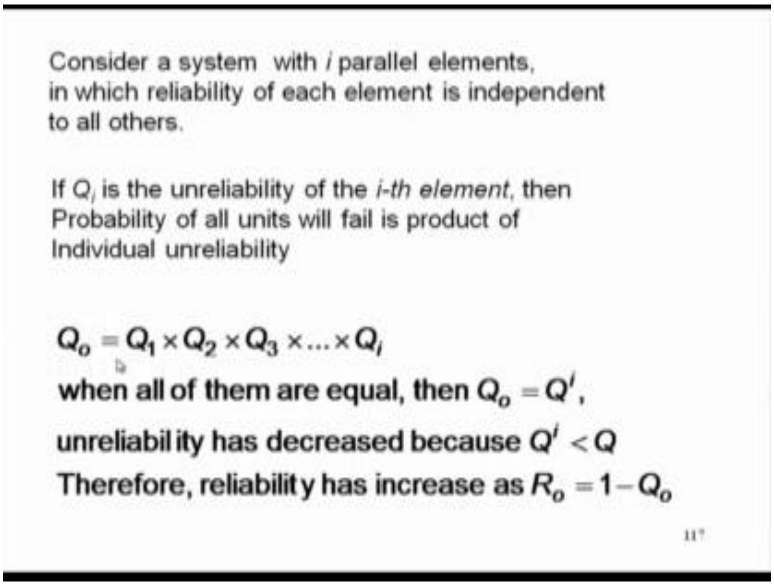

What is the overall reliability of two components in connected in parallel? When both are 0.9 by putting the same relation, R0 is equal to 0.99 because 1 minus 1 minus R1 into 1 minus R2 which is 1 minus 0.9 whole square is 0.99. When R0, R1 up to R3, all three components are connected in parallel and all of them are 0.9, you can see overall reliability is increasing 0.999. When two of them, it was 0.99. So, by increasing the number of components connected in parallel, you can increase the reliability number.

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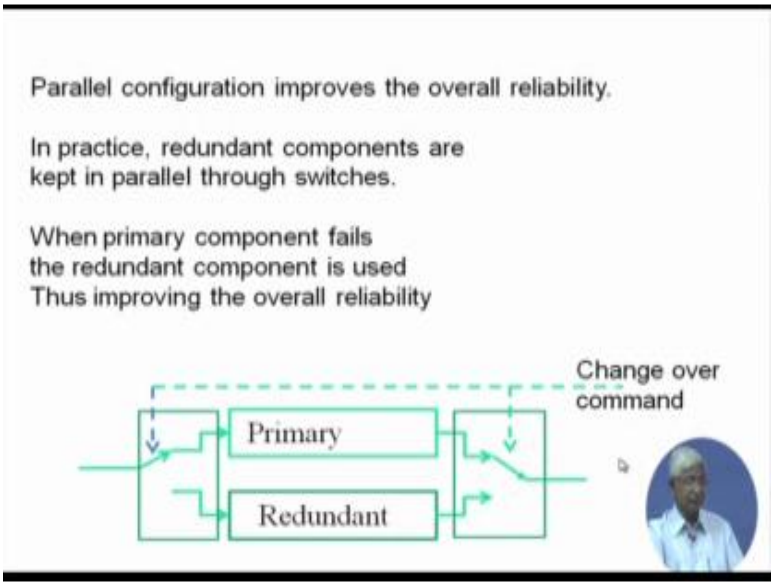

Parallel configuration improves the overall reliability. In practice redundant components are kept in parallel through the switches. When primary component fails, redundant component is used thus improving the overall reliability, but this change over is done by switch and command the switch reliability and this command reliability is also very important.

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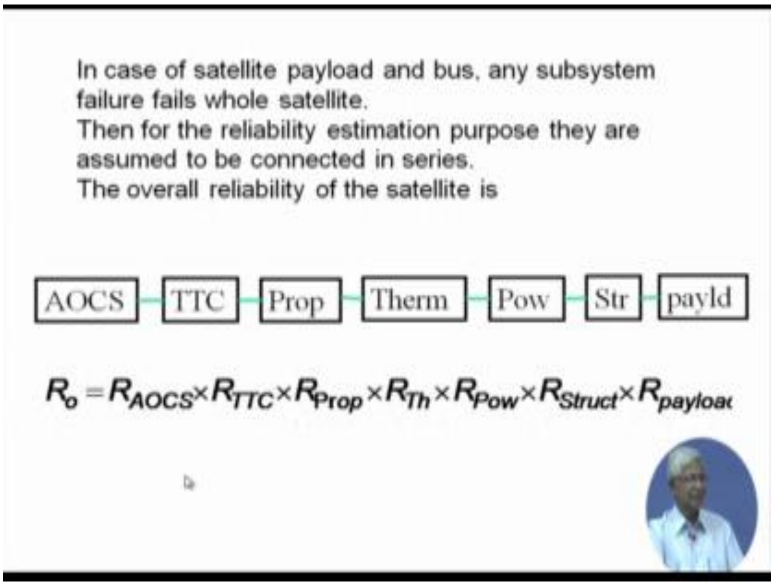

In case of satellites, all subsystem payloads, all have certain failure rates and on the reliability estimation is done as if they are connected in series. So, overall reliability of the satellite is as if AOCS TTC propulsion thermal etcetera payload everything is connected in series though physically. They are not connected in series is reliability purposes. So, overall reliability is reliability of individual multiplied overall reliability of the satellite.

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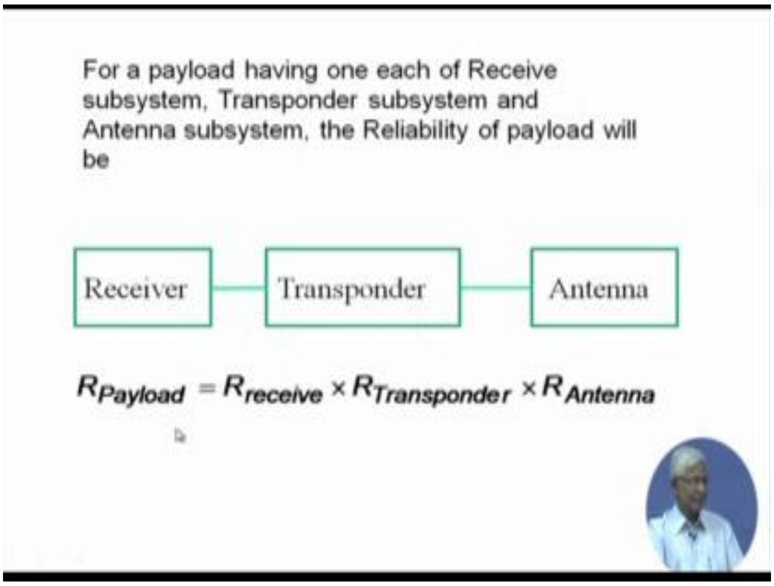

So, payload when one receives subsystem transponder system and antenna system is used, then it is multiplication of individual reliability payload. R payload is R receive R transponder R antenna.

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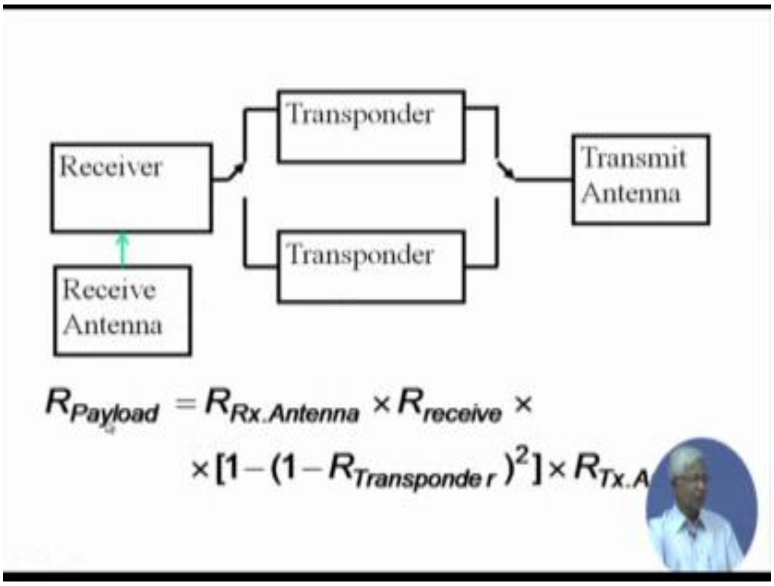

When transponder is connected in parallel and receive an antenna receiver and transmit receive antennas are in series, then it becomes over all payload reliability.

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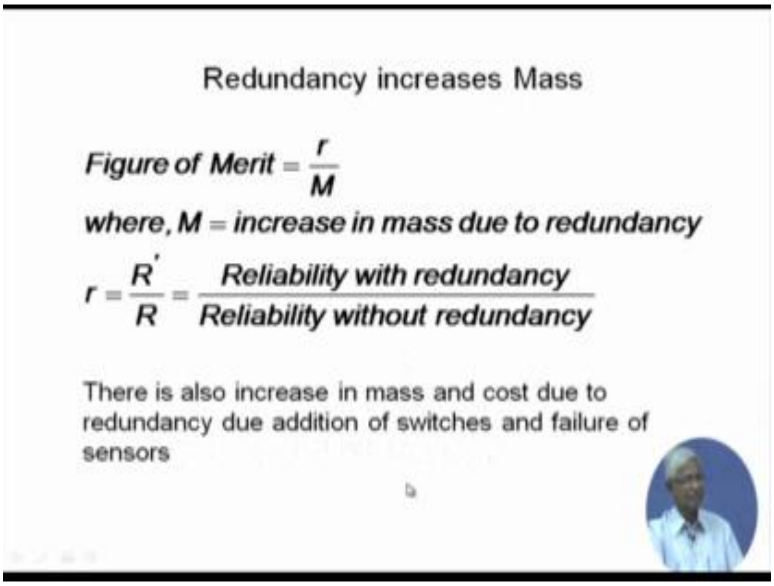

R receive antenna R receive multiplied by 1 minus 1 minus R transponder square because two of them are there into R transmit antenna. This redundancy increases the mass. So, therefore figure of merit is R by M. M is the increase in mass due to redundancy and R is the ratio of reliability with redundancy and without redundancy. There is also increase in the mass and cost due to redundancy due to addition of switches and the failure of sensors.

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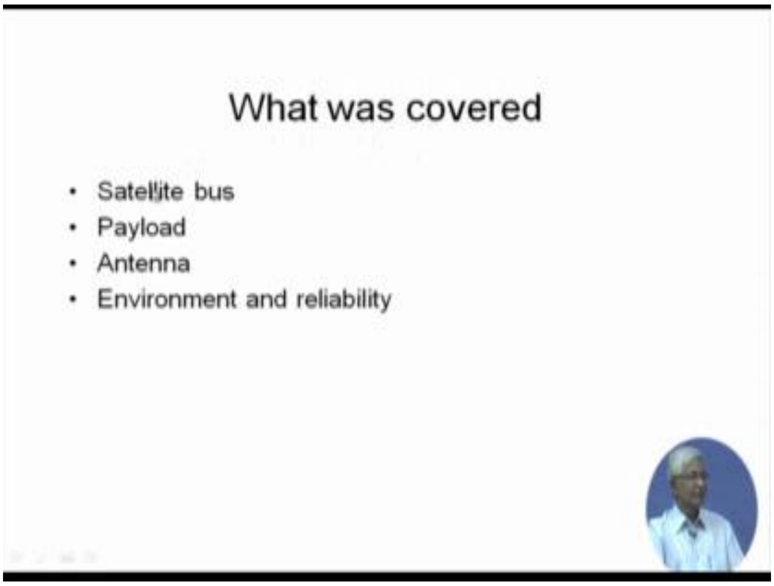

So, what we covered till now is satellite bus, payload, antenna, environment and reliability, where briefly we have covered the space segment. We stop here now.

Thank you very much.