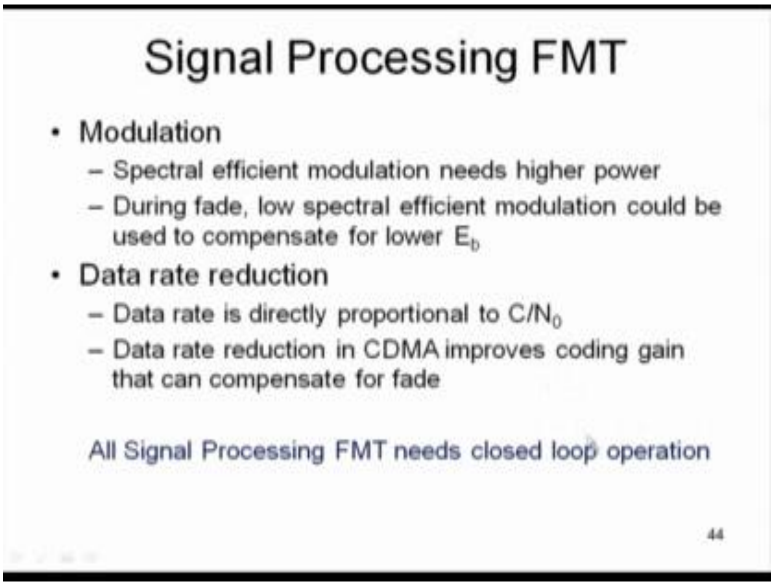
Satellite Communication Systems
Prof. Kalyan Kumar Bandyopadhyay
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture - 21
Propagation-3

Welcome back; we were talking about the fade mitigation technique and mainly we came up to signal processing FMT that is signal process fade mitigation technique after discussing the power control technique.

(Refer Slide Time: 00:36)



So, we go to this signal processing FMT on the modulation, we have seen this spectral efficient modulation needs higher power, that is higher order of p s k which is in one symbolic self mini bits can be put together which is may be a 8 phase p s k or 16 phase p s k or 32 phase p s k, you can have spectral efficient modulation, but that needs for a particular b e r, that needs higher power. Now during the fade, we have seen from the curve that is during the fade there will be a (Refer Time: 01:17) to maintain the same b e r, we can use a lower spectral efficient modulation that could be used to compensate for lower e b because of the fade the e b has reduced, c has reduced means the energy per bit e b also has reduced.

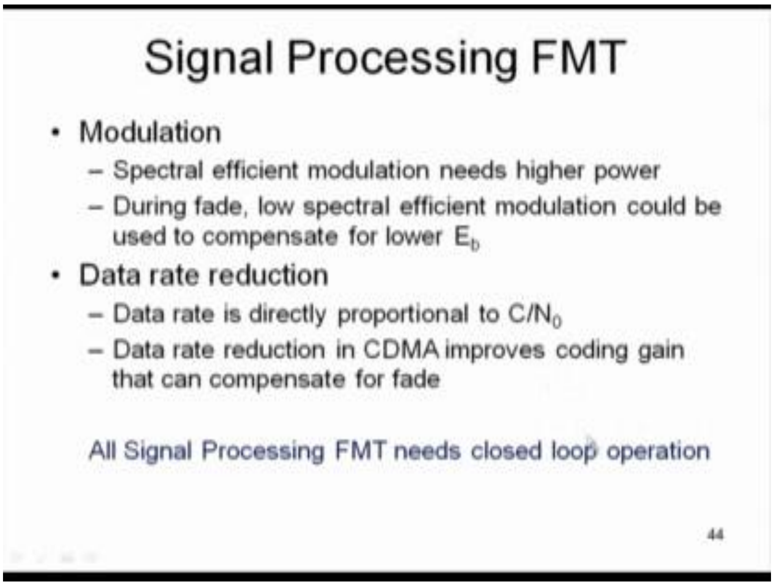
So, from higher spectral efficient modulation; we come down to lower spectral efficient modulation. So, band width will be requirement will be more, but we can manage the fade; there is a other technique is if you recollect, it was c by n knot is equal to e; b by n knot multiplied by bit rate or e; s by n knot multiplied by symbol rate. So, when the c by n knot has gone down, we can manage the same e; b by n knot and e; s by n knot by reducing the data rate, so data rate direction is another technique.

So, data rate is directly proportional to the c by n knot and data rate reduction is; obviously, give certain gain in the CDMA, that is code division multiple access, I hope some of if you have to studied this otherwise we will see this one when we will talk about multiple access techniques. So, where the data is spared using a code and the advantage is coding gain what we get, it depends on the how much is a spread divided by the data rate. So, as we reduced the data rate your gain increases, so coding gain has that can increase and that can compensate for fade, so CDMA technique can used.

Now, these all signal processing which includes the coding, the modulation and the data rate reduction needs certain closed loop operation; obviously, because the system is operating let us say between hub and a remote terminal signal, communication is operating and the communication texts; fraction of a second almost 250 millisecond going up and coming down, one hap. Now if the hop changes the modulation coding or the data rate certainly the remote terminals did not know. So, you should know the remote terminal should know; when to change and also what is the quality is reducing, the remote turn in that has to be monitored first and then change has to occur.

So, therefore, there has to be closed loop operation between the hub and remote terminal or remote terminal to remote terminal for all signals processing FMT.

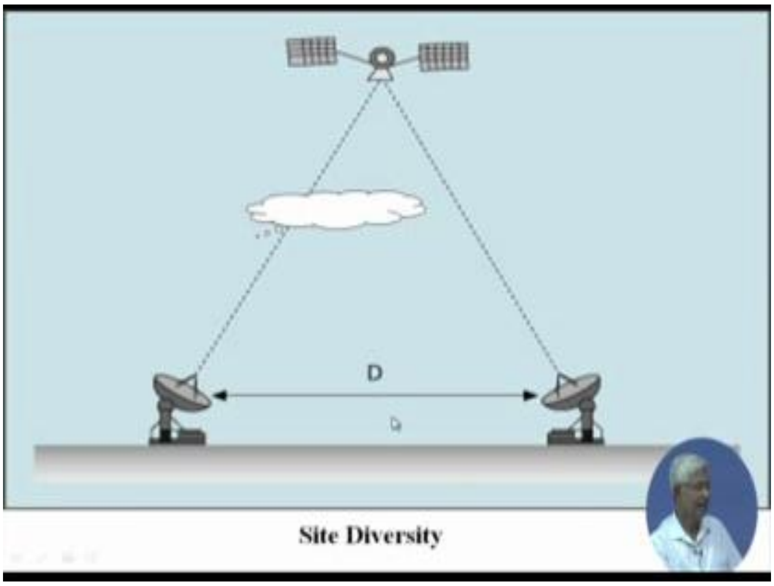
(Refer Slide Time: 04:02)



The other technique of FMT is the diversity, it is common sense that is if I use a site diversity in the signal path which right now we are using, might be having certain impairment, use another signal path we are this impairment is not there. So, it change the site is called site diversity either on the ground or on the orbit, so we can call it orbit diversity and also we have seen from the attenuation curve, that is when you go up in the frequency that is from k u band to k a band to b band, when you go up in the frequency; your attenuation is much more.

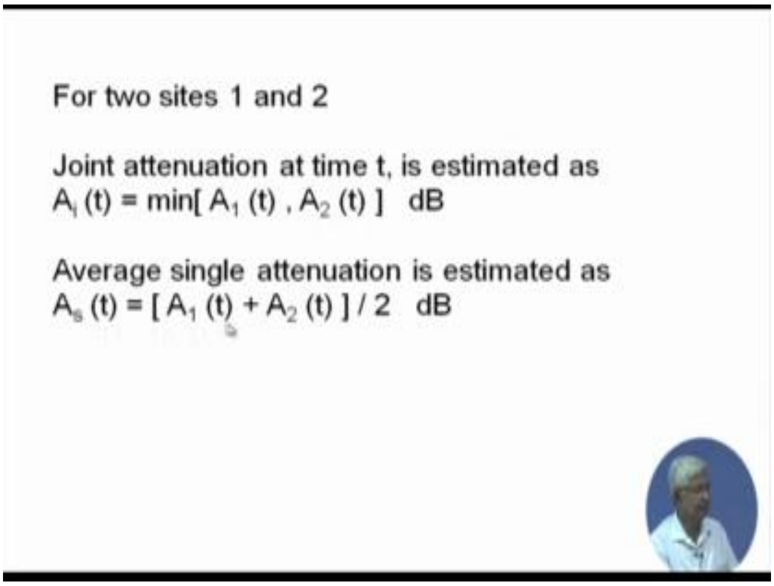
See we are operating at higher frequency band and because of attenuation either you can use power control or you can change frequency itself. So, the operation frequency can be changed, but each has their advantage and disadvantages or the other one is time diversity that is when you are operative that time and impairment is happening, the impairment may not be existing continuously. So, it will go away after some time, so you start communicating after some time, so that is called time diversity.

(Refer Slide Time: 05:23)



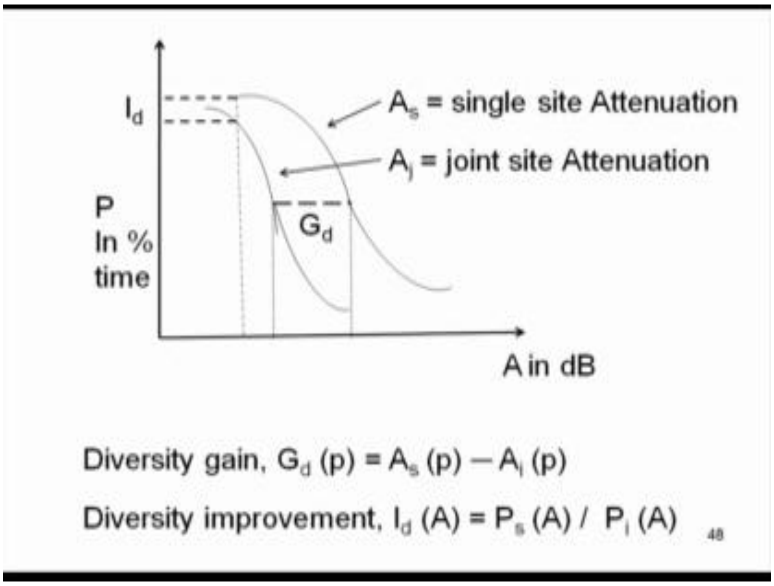
About the site diversity is shown here pictorially simple, that is the wanted path through which you are communicating has certain here it a cloud is shown actually impairment. So, you select another path where this satiation is not there or this interment is not there, now the distance between these two and you have to synchronize the communication between that, the distance between these two should be such selected because it is not mobile; it is fixation. So, such selected based on the historical data of how much this impairment spreads over this region, it may be a few kilometer; cannot be meters, it will be few kilometers or few tens of kilometers sometimes for highly reliable links people use these type of system.

(Refer Slide Time: 06:14)



We will show you very quick some models proposed by International Telecommunication Union for these type of diversity. Let us take a two sites, site one and two and joint attenuation at time t is estimated as A j, that is A j function of t is minimum of A; 1; t and A; 2; t, d B and that average single attenuation is estimated as A s that is single attenuation, so A s t is A 1; t plus A 2; t by 2 there is an d B.

(Refer Slide Time: 06:56)



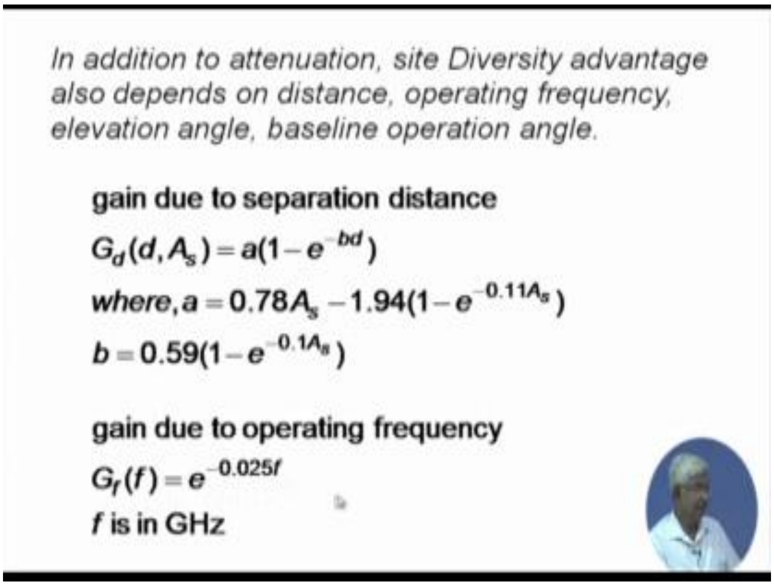
So, this A s and A t; if it is plotted in terms of probability of time this A is plots like this just a typical plot and A j plot is like this. So, that even see at the joint site attenuation;

you have for the same probability in time, you have certain gain; you have less attenuation, so this is defined as G d that is the gain due to diversity.

So, diversity gain in terms of probability is A s minus A j in dB, but there could be other way that for a particular attenuation, for some probability some time for less amount of time, you will get the advantage that is in terms of probability using the joint site attenuation which is called improvement. So, improvement is defined as I d, so diversity improvement is I d; A is P s; A by P j; A, this is P s; A and this is P j; A, so ratio of that you get a improvement for a particular attenuation in terms of probability, in terms of time how much time you get the link available, whereas here you get attenuation in any particular probability of time, how much attenuation advantage you get that is in terms of diversity gain.

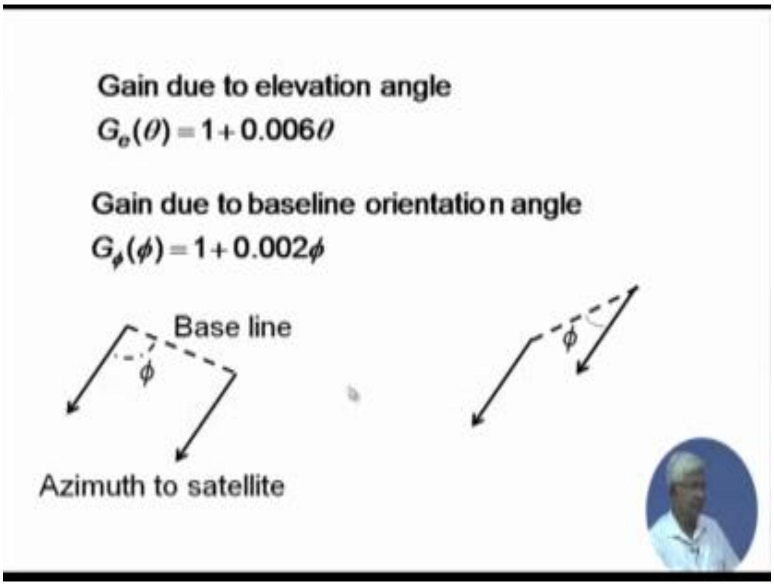
Now, these are modeled by i (Refer Time: 08:36) and I will show you very quick just for information, I will give some example also.

(Refer Slide Time: 08:41)



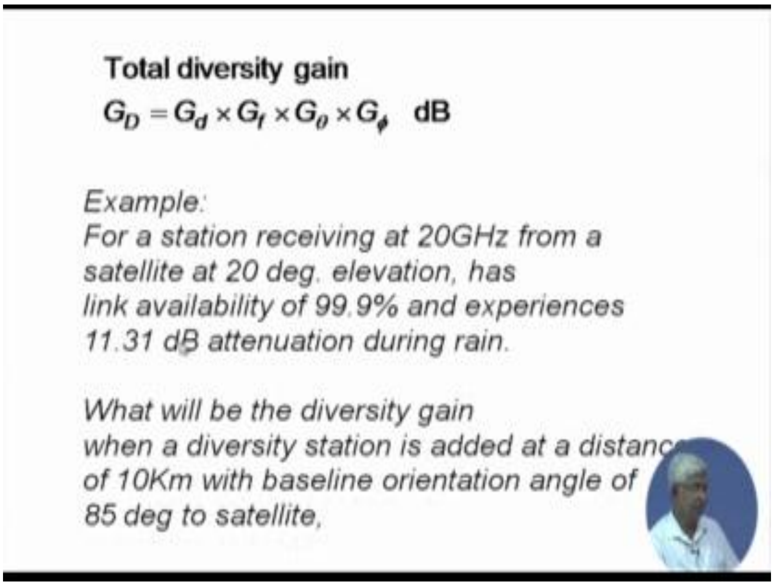
In addition to attenuation, site diversity advantage also depends on the distance, operating frequency, elevation angle; baseline operating angle itself, each of them is modeled. Gain due to separation of the distance G d is a function of d; distance and the single site attenuation is modeled as 2 co efficient; a small a and small b, a into 1 minus e to the power minus dB, where a is given as 0.78 of A s minus 1.94 into 1 minus e to the power minus 0.11 A s and b is given as 0.59 into 1 minus e to the power minus 0.1 A s, these are modeled available from ITU and the gain due to operating frequency that is gain due to separation of distance G d. Gain due to operating frequency; G f is e to the power minus 0.025 f; f is in gigahertz.

(Refer Slide Time: 09:57)



Then gain due to elevation angle is G e, function of theta; elevation angle 1 plus 0.006 theta. Gain due to the baseline orientation angle towards the satellite because two sites are used G phi; phi is the baseline orientation angle with respect satellite G phi is function of phi is 1 plus 0.002 of phi less you can see picture the baseline this now the directly this phi is almost 90 degrees towards the satellite. If the baseline is slightly different oriented, so you can see the diversity; this much distance you get whereas, here you get distance this much distance diversity advantages, so it based on the azimuth towards the satellite where is the baseline.

(Refer Slide Time: 10:48)



Now, the total diversity gain G capital D is multiplication of all these diversity gains that is in terms of distance G d in terms of frequency G f in terms of elevation angle theta in terms of baseline angle azimuth angle G phi and a quick example, you just walked out here just for your information that is for a station receiving at 20 gigahertz from a satellite at 20 degree elevation has link availability of 99.9 percent and experiences 11.31 dB attenuation during rain.

Now what will be the diversity gain? When a diversity station is added at a distance of 10 kilometer with baseline orientation angle of 85 degree satellite, the reason for train you this type of just an example is to get familiar with some amount of number how much of advantage you get; you can see there is this is k a band operation, 20 gigahertz and you can see that there is a diversity distance of 10 kilometer, available in number is 99.9 and at this 20 gigahertz for a particular range it, you get 11.31 dB attenuation.

So, what would be the diversity gain, the number total diversity gain number; so each of the G d, G f, G theta and G phi has to be calculated based on the numbers which are available here simple.

(Refer Slide Time: 12:15)

$$a = 0.78 \times 11.31 - 1.94(1 - e^{-0.11 \times 11.31}) = 7.44$$

$$b = 0.59 \times (1 - e^{-0.1 \times 11.31}) = 0.4$$

$$G_d = 7.44 \times (1 - e^{-0.4 \times 10}) = 7.3$$

$$G_f = e^{-.025 \times 20} = 0.61$$

$$G_\theta = 1 + 0.006 \times 20 = 1.12$$

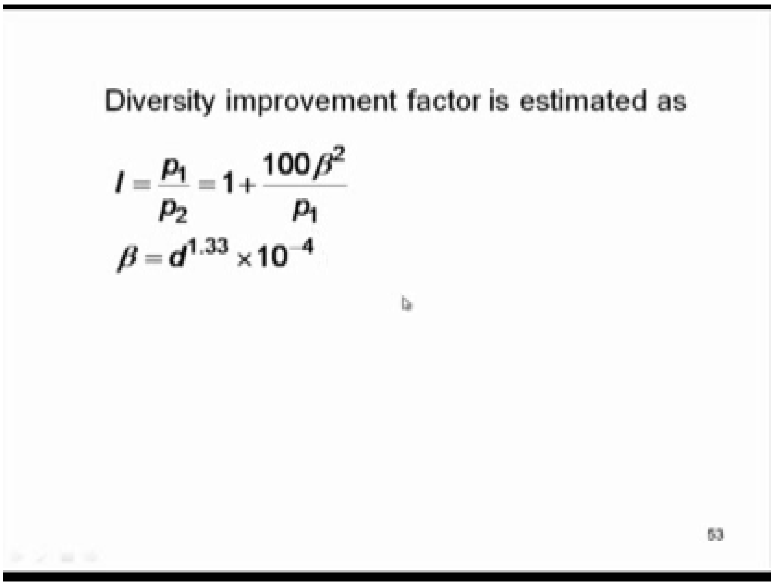
$$G\phi = 1 + 0.002 \times 85 = 1.17$$

$$G_D = 7.3 \times 0.61 \times 1.12 \times 1.17 = 5.84\ dB$$

That is first you calculate the co efficient a, based on that model earlier I mentioned and then co-efficient b based on the same model. So, using those a and b you find out the G d, then based on the frequency which is in gigahertz; you find out G f, based on the elevation angle; you calculate G theta, based on the baseline azimuth angle G phi and multiply all of them, you get 5.84.

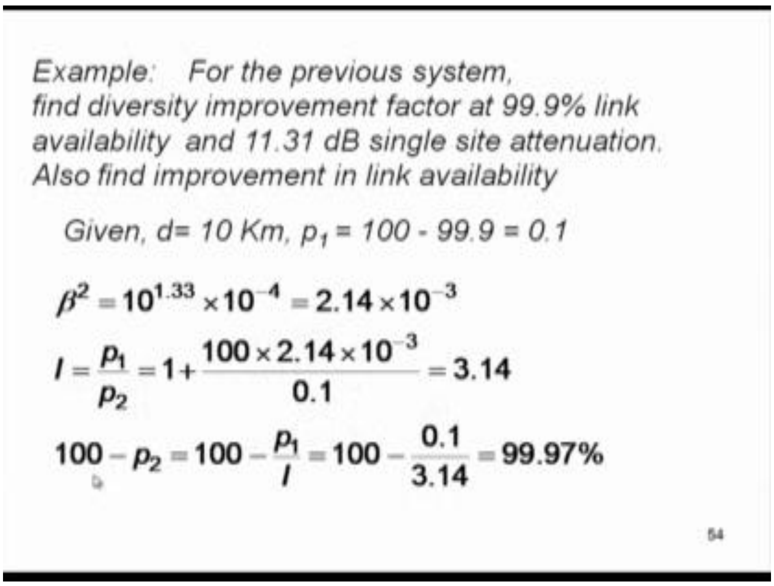
So, which almost you will see 10 kilometer distance; you get a where you were loss was 11.31 dB with 10 kilometer distance, you get a advantage of 5.84 dB, so almost half of that you have gained with this, just to show you that number.

(Refer Slide Time: 13:04)



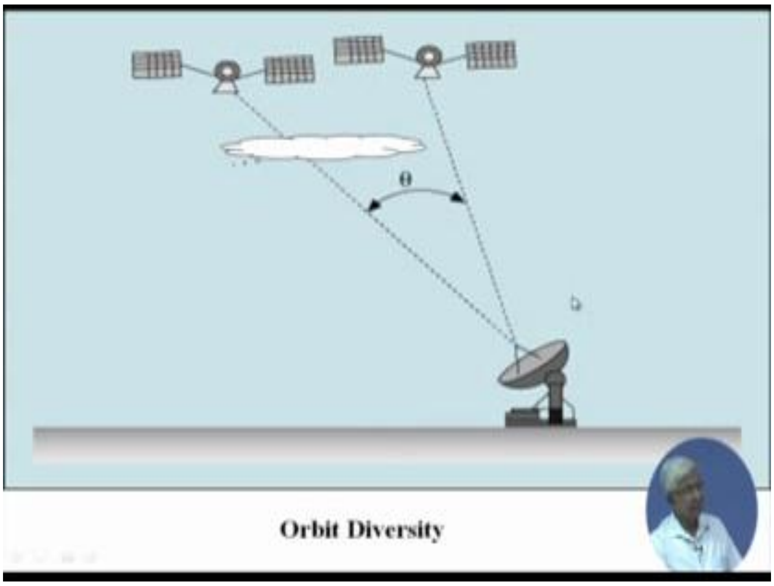
Similarly diversity; this is diversity gain what you seen, similar diversity improvement factor can be estimated that is I is equal to p 1 by p 2 and that is the probability of different single diversity to joint diversity is equal to 1 plus 100 beta square by p 1, beta is modeled as in terms of distance d to the power of 1.33 into 10 to the power minus 4. This is again in the model given by ITU and we take another example, all most the previous system number; that is the find diversity improvement factor for 99.9 percent of link available and 11.31 dB single site attenuation. Find the improvement in link availability.

(Refer Slide Time: 13:40)



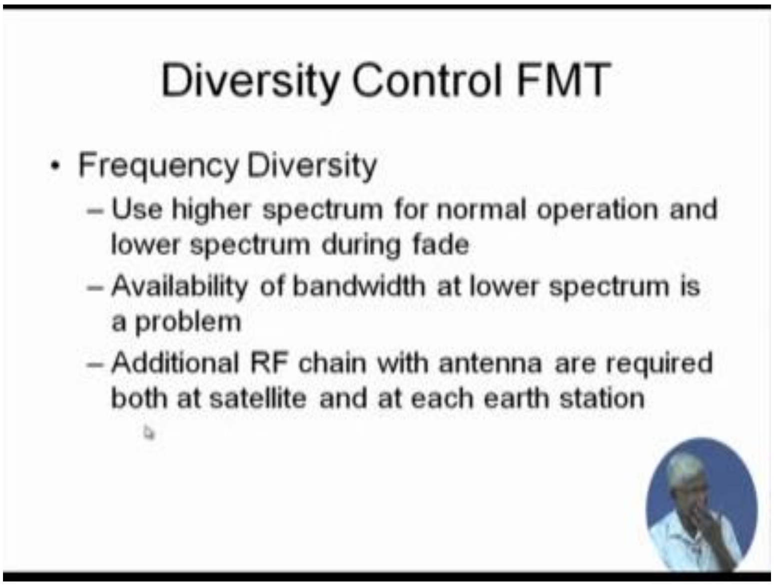
So, first you find two things diversity improvement factor and then find whether improvement in the link availability happens or not. So, given these numbers you can find out the p 1 and then beta square and then I; which is ratio of p 1 and p 2 and then that is the diversity improvement factor and then link availability is 100 minus p 2 because of the p 2 sites is added. You increase the link availability from 99.90 to 99.97 percent, so this is another example of improvement factor finding and availability improvement of that.

(Refer Slide Time: 14:51)



Now, there are certain conceptual ideas that you can use different orbit, so the satellite visibility there wanted link you have impairment, so go to another satellite. So, you have to either use the different antenna or turn the antenna of the other station and you have to select such orbit so that impairment does not take place. Normally you people do not use these things, these are the almost simulation or theoretical ideas, and so with the angle theta you get certain orbit diversity.

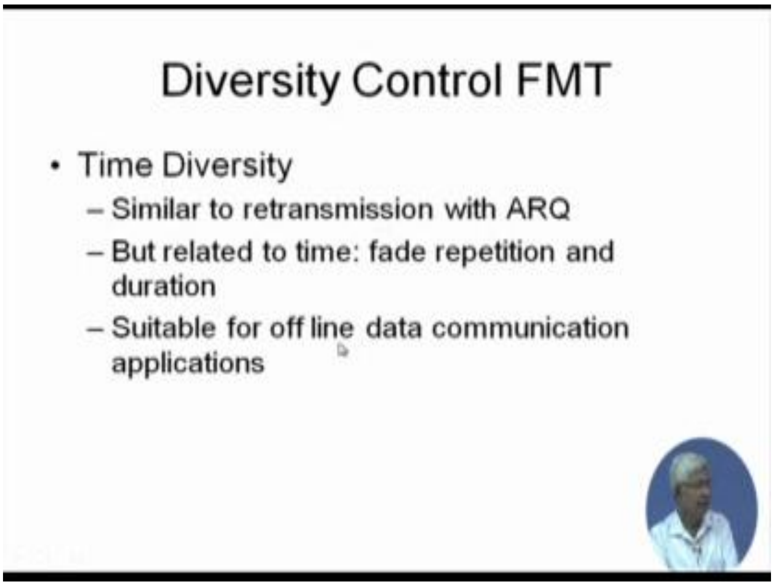
(Refer Slide Time: 15:24)



You can have frequency diversity; we have seen that higher spectrum, normal operation and lower spectrum during fade. Normal operation you can use as spectrum, many advantages and when fade occurs since the higher spectrum has large attenuation, you come down to another spectrum at this attenuation does not exists or reduces, but then of course, you understand the difficulty in these that you have to have at two frequencies compete up link and down link can both in satellite both link and you know, if you have a network in all the (Refer Time: 16:05) systems should have these and availability of bandwidth at lower spectrum is a problem because just briefly we have mention in one of the slides the earlier that at c band, we have 700 megahertz allotted by IT for space to earth, earth to space link and at k u band it is roughly of that 2 gigahertz, at k a band is roughly about 2.5 gigahertz.

So, at higher and higher band you have allotted larger bandwidth, so if you are operating at higher band and suddenly you try to change over to lower band, you may have some problem of bandwidth at the lower spectrum and then of course, as I mentioned that additional RF chain with including the antenna are required both at the satellite and at each a station that is required.

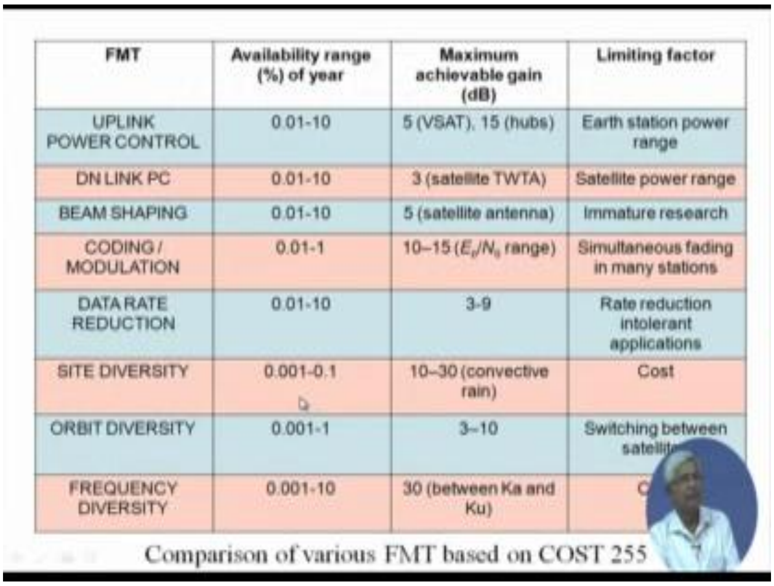
(Refer Slide Time: 16:54)



Now, the other technique is time diversity. Time diversity means a similar to retransmission with Automatic Repeat Request, that it at higher layer what we do that is data rate control layer; this cannot be used for real time operation say you have a audio conversation going on or video communication or video broadcasting going on, that time you cannot wait; suddenly stop the transmission and wait until the impairment goes away. A rain event is taking place for few minutes, after that you start discussion on the video conferencing, let us not tolerable.

So, these are all for non-real time communication that is used and then these are how much time later you will do this repeat transmission or retransmission or continued transmission is based on the fade repetition rate and the fade duration which is average value has to be measured earlier and in real time also it has to be monitored carefully, if you recollect that particular slide, where the fade threshold is shown and different fade events and non-fade events are shown. So, based on these things the duration for which the transmission is not going on that has to be estimated, so mostly it is offline communication like e-mail, when you do e-mail communication then this is a quite suitable that is what is listed, so they all for offline data communication application.

(Refer Slide Time: 18:34)



FMT	Availability range (%) of year	Maximum achievable gain (dB)	Limiting factor
UPLINK POWER CONTROL	0.01-10	5 (VSAT), 15 (hubs)	Earth station power range
DN LINK PC	0.01-10	3 (satellite TWTA)	Satellite power range
BEAM SHAPING	0.01-10	5 (satellite antenna)	Immature research
CODING / MODULATION	0.01-1	10–15 (E_b/N_0 range)	Simultaneous fading in many stations
DATA RATE REDUCTION	0.01-10	3-9	Rate reduction intolerant applications
SITE DIVERSITY	0.001-0.1	10–30 (convective rain)	Cost
ORBIT DIVERSITY	0.001-1	3–10	Switching between satelli
FREQUENCY DIVERSITY	0.001-10	30 (between Ka and Ku)	C

Comparison of various FMT based on COST 255

Now with all these things, we have this is taken at table is prepared by like a committee called COST 255 and different type of fade attenuation techniques they have analyzed and some of them are simulated and what we shown here is the fade attenuation technique list and average range of the year when the impairment takes place or I should say the availability and I should say non availability, availability of this FMT average change of the year and using that what should be the achievable gain, they have estimated in dB and what could be the limiting factor for each of them.

This list has to be seen carefully, some of them are similar to some of the experimented. Using uplink power control, you should look at this particular column; this third column which shows that maximum achievable gain. For VSATs you get 5 dB, for you can get 15 dB advantage; you can see this reason is at hubs, we will discuss on ground station; during our topic on ground station. VSATs are very small aperture terminal, so for very small aperture terminal you have all facilities which are available at the terminal are small.

So, you cannot put a very large power amplifier there, since it is a power control uplink; power control the; whatever power amplifier and preference normally put into the VSATs, you can vary about 5 dB or so that is why here it is slow, whereas at the hub you have a large station and you have all the availability resources for putting 10 times or 15 times more, much larger than that and it is this in dB, so much much larger 17 times more the amplifier capacity.

That is uplink of power control you have defects based on different sizing of the terminal you get, the down link power control normally satellites you have a 3 dB gain advantage you put, but the disadvantage in this if you are we had discussed earlier that you will be operating normal operation that is none fade duration operation. You will be operating at much lower back up, so even with 3 dB increase in e i r p you not enter in to the none linear region. So, normally you will be most of the time you will receive 99.9 percent of the time you are operating and in the 0.01 percent of the time, you will be introducing this fade mitigation. So, rest of the time you will be operating at much lower power 3 to the less power, to compensate for the down link power control you will be using only during this time for 3 dB addition power not very advantageous, but this is possible.

Now, beam shaping is a idea there were only till now very few people have experimented commercial, not I am not at least have a; that means, see during the fade; you change the pattern of the antenna itself and so that the areas which are getting the fade or rain there you are providing larger antenna gain by shipping the antenna b. You do not touch the power amplifier, in that process you see the inter modulation products are adjacent channel interference, but your problem is that the satellite antenna becomes very complex.

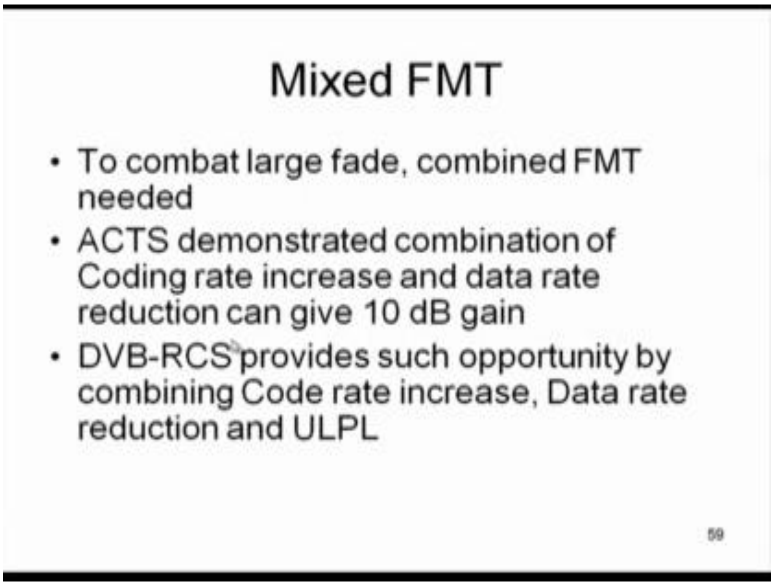
Normally these are designed with the complex array antenna with additional fade phase and amplitude adjustment. So, these are in the research level and those; these when this cost committee was working is that the is settlement, even now I am not aware at that any commercial things are available, commercial antenna beam shaping for fade control; beam shaping is done, but for fade control measure fade mitigation measure, this is not being used I think (Refer Time: 23:07) at was trying for this.

The other FMT which is the signal processing FMT, it is the coding and modulation change and this is commercially being used in our VSAT network using d v b r c s second generation and using even d v b, they are using some of the coding modulation techniques where you get advantage of e b by n knot by changing we have discussed just now, by changing the from higher order of modulation has (Refer Time: 23:46) efficiency come to the lower order modulation or from lower order coding to higher order coding. If you go in both the cases you have disadvantage in terms of bandwidth, but the power wise, you gain a very good power level that is almost 10 to 15 dB of power advantage get to maintain the same b e r or symbol error rate, using the same e b by n knot; by changing that e b by n knot same b e r. So, 10 to 15 dB is quite large number compare to the power control FMT are either from the down link or up link power control.

The other technique is data rate reduction, we just now discussed there also you get quite a good amount of achievable gain, which is 3 to 9 dB of data this order, but you know it depends on the type of service, type of application you are using for this type of service suddenly you change the data rate for real time operation, it may not be acceptable to the user, but it depends all the type of the service, type of the user they may tolerate lower data rate, but try to maintain the availability as the same number, but again as I said at for file transfer or e-mail type of non-real time application, this could be used may take a little more time to transfer the volume of data, but you do not; you have the availability of the link.

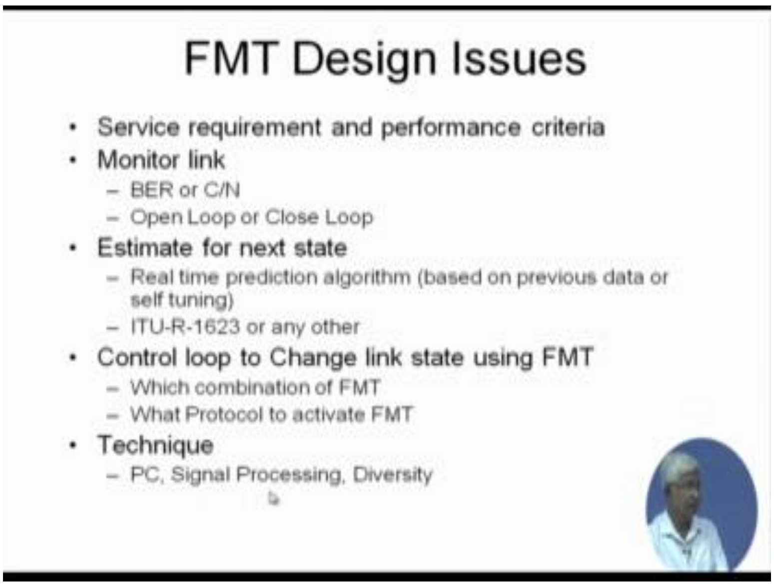
Site diversity; obviously, you get a good amount, our calculation shows that you get some amount, but by changing the distance much more you get a almost 10 to 30 dB is convective rain, they have done some experimentation most probably, but you need a two different station, so your cost is increasing; orbit diversity is again is almost assibilation or theoretical idea that is you would have to use two satellites, again distance are different angles of that may give you a large amount of gain frequency diversity is also terrible cost because 2 separate frequency chains up to up link and down link as we met both this stations as well as satellite; you though you get very large advantage that is 30 dB, but the more as we see that commercially this coding and modulation is most popularly used and power control is also used.

(Refer Slide Time: 26:30)



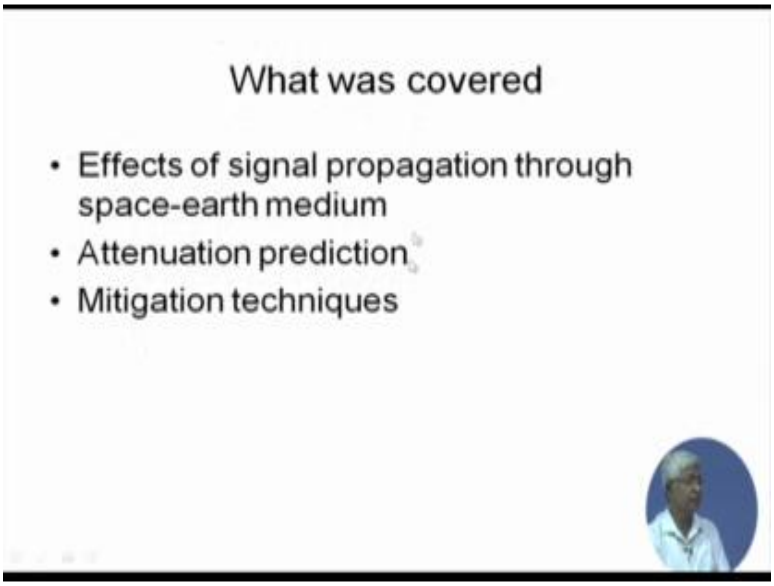
But people are not individually trying; they sometimes combine these techniques and get higher advantage which is called mixed FMT combat large fade combined FMT. So, acts advance communication technology satellite demonstrated combination of coding rate increase and data rate, it was done in 1990s by US, it could show those in 10 dB gain DVB-RCS provides, DVB is Digital Video Broadcasting and RCS is a Return Channel wire Satellite. So, this is used by VSAT communication what you see in bank ATMs they are use in this is standard by European community provides such opportunity by combining coding rate increase and data rate reduction and up in power control.

(Refer Slide Time: 27:09)



They are many design issues, service requirement performance criteria and as you have listed earlier monitor the link BER, whether you decide whether open loop, close loop then estimate the next state which needs the prediction algorithm, real time prediction algorithm and there are certain (Refer Time: 27:26) standard on that control loop to change the link state using FMT, which needs combination of which combination of FMT has to be is for protocol to activate FMT and the techniques which is power control signal processing in diversity.

(Refer Slide Time: 27:40)



So with all these, what we covered is effect of signal propagation through space earth medium, attenuation prediction, mitigation techniques. So, with this we close this propagation; signal propagation through medium and the effect and that mitigation for that.

Thank you very much.