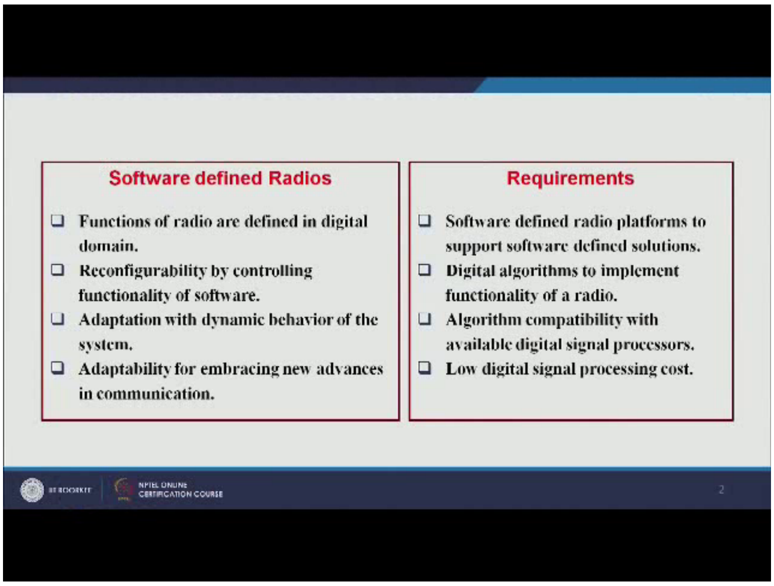
Basics of software-defined radios & practical applications
Dr. Meenakshi Rawat
Department of Electronics & Communication Engineering
Indian Institute of Technology, Roorkee

Lecture – 01
Foundation for software defined radio

Hello everyone, today we are covering the basics of software defined radios and practical applications and it starts with the definition of software defined radio and related challenges. So, what is software defined radio? As the name suggests, it has 2 portions, one is software.

(Refer Slide Time: 00:38).



And then, one is radios. So, whenever the function of a radio that are defined in digital domain, it is defined at as software defined radios. Initially in us defense labs in 1970s, the work is started where they have started implementing the functionality of any receiver in digital domain. Eventually in 1990s, one geometer law in his cases, he proposed this terms software defined radio where most of the functions of the radios are given in the digital domain. So, what are the requirements here if you look at the slide, it provides reconfigurability by controlling functionality of the software and it should be able to adopt with the dynamic behaviour of the system.

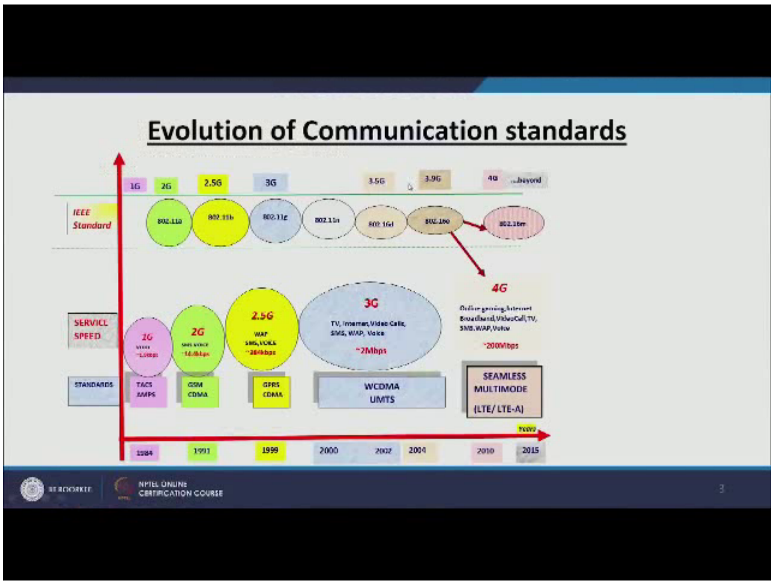
So, conventional radio when we are talking about it, it contains a particular frequency for particular amplitude and particular format, but when we say software defined radio it should be able to switch between this different parameters. Moreover, because we are moving towards a new age new era of the communication system, there should be adaptability, so that we can embrace then you advances in communication. So, when these are the software defined radio bullet points what are the requirements that are that are required here. So, the requirements are that, software defined radio platform should support software defined solutions. So, first of all we have to have that platform. So, it have a good it should have a good analog solution as well as platforms, which should have a inbuilt DSP which can support this kind of solutions.

Second, as the name suggests software is a part of this software defined radios. So, there would be some digital algorithms to implement functionality of a radio. Then we should have some algorithms which will be do it exactly what we are proposing there and then there should be algorithm compatibility with the available digital signal processors. What do you mean by the compatibility?

There are 2 things first of all you are proposing something in a ideal amendment, but then when you want to put it to digital signal processors, that processor might be your pc that might be your FPGA or you know some platform such as ubuntu based platform. So, if it is a floating point and environment you can have the algorithm which are working perfectly find there, but then there are some platform which are low cost and they utilize FPGA etcetera. In that case your algorithm should work very nicely in a fixed-point computation environment.

Apart from that what as we require, we should have the low digital signal processing cost because we are doing everything in digital domain. What is the motivation for going for the software defined radio? Initially when we used to have simple commission by using a radio which we use at our home for you know, listening to cricket commentary etcetera that was analogue communication based you should have seen the am tuning or fm tuning there, but if.

(Refer Slide Time: 03:55)



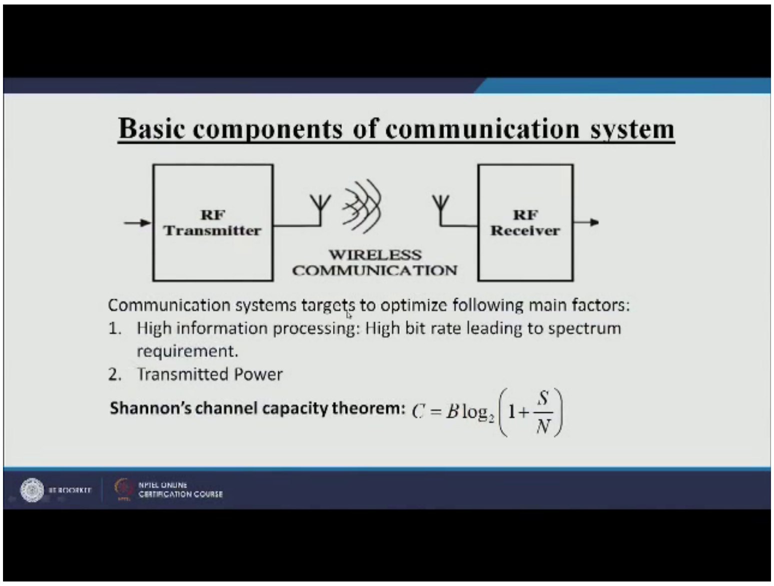
You look at this evolution of communication, the standards you can see that even initially for the first it was only voice, then we came to sms and voice, more applications added there now eventually and 3GTV internet video calls sms and voice all of them was there. Today, we have reached the stage where we are using 4G and it is a seamless multi boot it also have online gaming video calls as on top of that, the previous TV sms and voice applications. So, we are increasing in the terms of generations. So, if you look at the IEEE standards, they have the different versions of the same standard. So, it was 802.11a then we went to b de, n we had something called g and BGN all 3 versions they support WLAN Wi-Fi then in the LT which is 3G and 4G combination.

We have seen more application added there, Now if you look at their speeds, it was initially for first generation, 1.9 kbps for 2Git was 14.4 kbps and then it keep increasing in 4 4G we propose to have 400 mbps and finally, we are moving towards 5G and in the 5G we have very ambitious goal of getting one GBPS speed.

So, we are targeting more and more mbps that is data rate and for that we have to have more complex communication standards and modulation techniques and when you are talking about this modulation techniques, we they cannot be achieved with the analogue a platform because, analogue have their inherent fabrication errors etcetera. So, it is in becomes the motivations for the software defined radio. So now, for the software defined radio first of all we have to go through the basic components of the communication system, analogue portion and the digital portion, the basic concept and then, we will see what are the limitations which are which we have to target there.

So, communication system basically targets to optimize 2 factors first is high information.

(Refer Slide Time: 06:12)

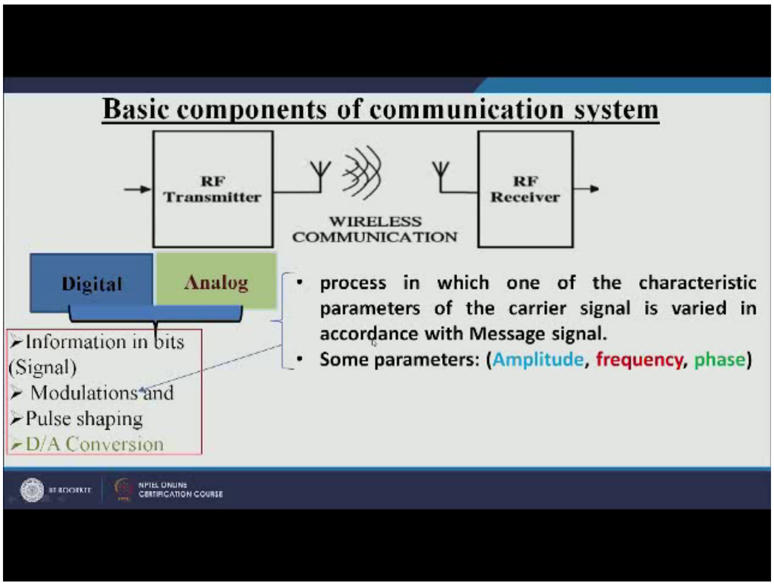


Processing means we want to be able to send more bits; more bits means more information which you want to have send thereand second is the transmitted power why is that if you look at the Shannon's channel capacity theorem. That channel capacity is given as the bandwidth of the signal multiplied with the log base to 1 plus signal to noise ratio. So, any signal which have a good signal to noise ratio, good dynamic range it has better capacity, moreover, it has the capacity has the direct relation with the bandwidth of the signal.

So, when we look at this to get more at the rate we have to have more broadband system and if most of the providers they are looking for a broadband system, then we have the deficiency of the a spectrum. So, there is a requirement of this spectrum there. Moreover, we have to have good enough transmitted power because when you want to transmit a signal through a particular medium to a long distance, you have attenuations; you have you know it is bouncing from different mediums.

So, basically the power goes down. So, in that case we have there enough transmitted power that it can it can reach to the final and there moreover, this signal to noise ratio we have to keep high enough power of the signal with respect to noise so, that we have good bit rate there. So, keeping these 2 requirements in mind we will go through the basic components of the communication system and then we will go to the basic SDR applications and what are the hindrance they are what are the limitation bottlenecks there and we will try to solve them. So, in a particular digital communication system we have a RF transmitter and one RF receiver.

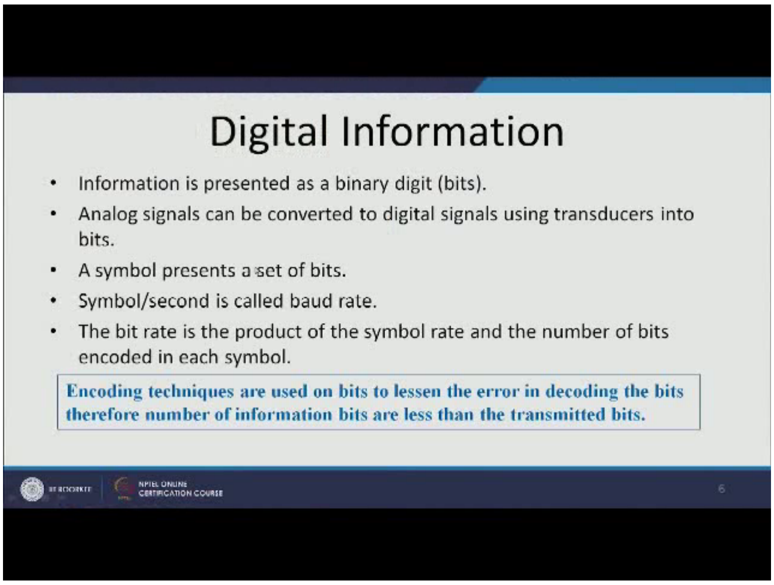
(Refer Slide Time: 08:17)



This is a wireless communication system where our medium is basically just the air through which the signal is being transmitted. So, it has different portions; first of all, we have digital portion which is inside the RF transmitter and what are the parts of this digital system because they make the basis for a software defined radio.

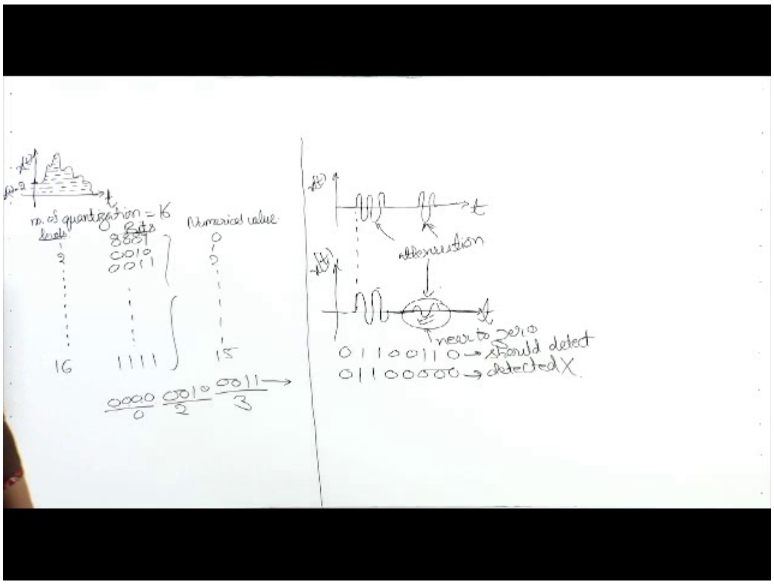
First of all, you should have a information bits. So, whenever you have some data, it is represented in terms of binary digits what we call? Bits. So, basically, they are given in terms of 0 and 1s.

(Refer Slide Time: 08:59)



So, whenever you have a signal.

(Refer Slide Time: 09:03).



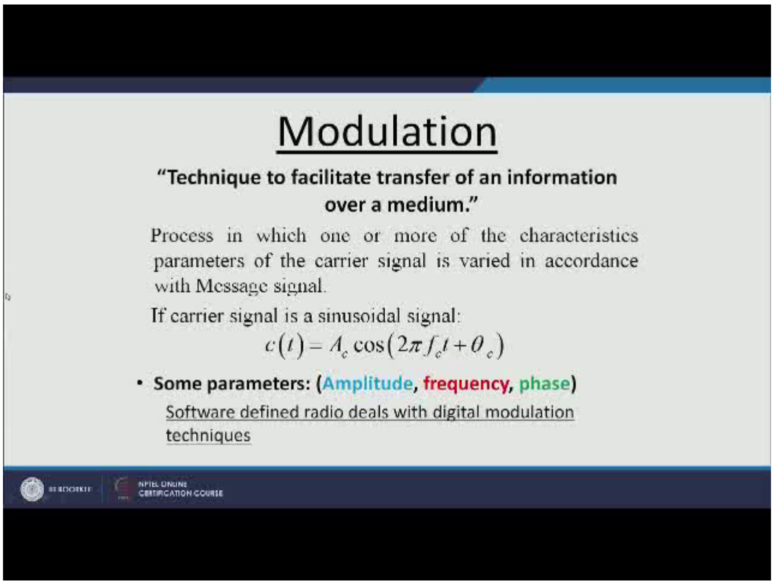
This coming in time t if suppose it is a analog signal it will look like this basically in the signal when we do the quantization. So, depending on the level of quantization, you will create bits for example, if this number of quantization is equal to 16 it means we have to represent our system in the 16 levels. So, by that definition if we have to have 16 bits, what is their binary representation and the last one is this. So, you have 16 levels it is number of levels and these are representation and they signify basically numerical value which is 0 1.

So, 0 will be corresponding to 0 0 0 0, 1 2 and up to 15 and it is showing 16 different levels. So, this information if I want to represent 0 it will be 0 0 0 and then suppose, I want to read this value and this is corresponding to 2 right. So, after that it will be 0 0 1 0 if I want to send 3 after that it will be 0 0 1 1. So, you can see it is a stream of binary digits which you called bits. So, it has only 2 states either 0 or 1.

So, basically, we can represent our information in this form. If it is analogue, we can convert it back into digital and represent it like that. So, basically once we have our stream of bits symbol presents a set of bits, it means a symbol can have either one bit or more than one bit it can be 2 4 8 16 depending on the modulation we have chosen. Now symbol per second it is called baud rate. So, normally we propose that we this is our symbol speed. At this is speed base sending our symbols and inside one symbol you can have many bits. So, you can imagine that bits are like balls maybe it is white color ball and red color ball and when you compile them when you put them in a box those boxes suppose contain 4 balls at a time. So, each box is representing symbol there and this is how we say these many box we have communicated now bit rate is the product of symbol rate and the number of bits encoded in in each symbol.

Now, encoding techniques are used on bits to lessen the error in decoding the bits therefore, the number of information bits are less than the transmitted bits. So, those bits which we are using for the encoding are also used eventually although they are not useful bits, but they are useful for detecting the error. Now, coming to the second part, which is the modulation. So, first you have your information bits you map between particular symbols after keeping some bits for the encoding now we come to the modulation.

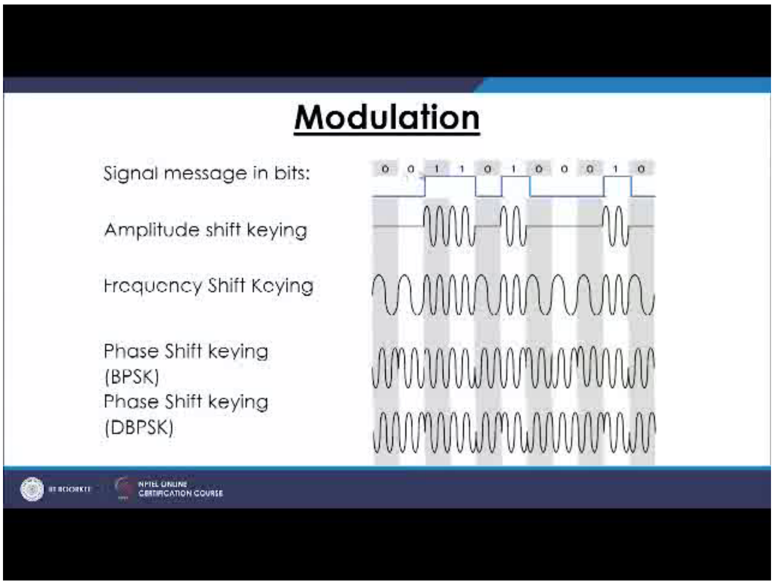
(Refer Slide Time: 13:13)



So, modulation is a technique to facilitate transfer of an information over a medium. So, basically process in which one or more of the characteristic parameter of the carrier signal can be varied in accordance with the message signal we called it modulation. For example, suppose our carrier signal is a sinusoidal signal. So, this is the equation for the sinusoidal signal we have amplitude their phase and frequency. So, whenever we vary any of these thing then, it becomes modulated in terms of that parameter. So, because software defined radio deals with the digital modulation techniques.

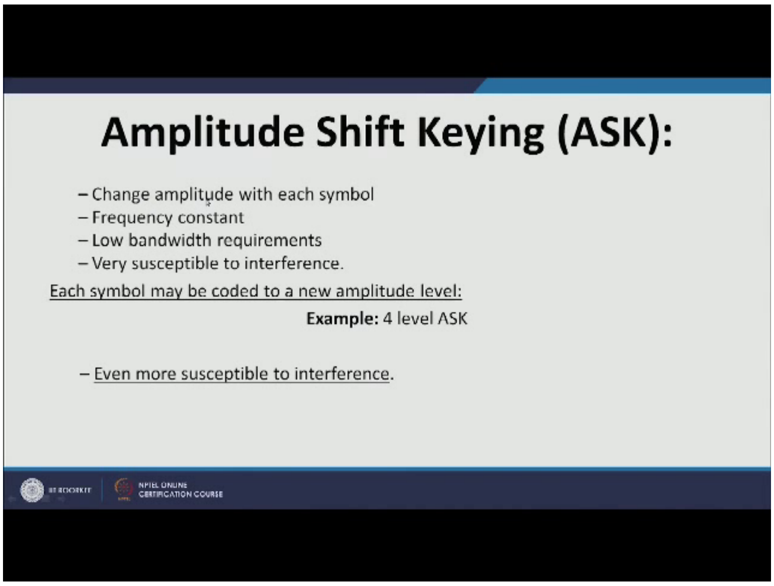
So, we will be just stick to that we are not going into the analogue portion there.

(Refer Slide Time: 13:58)



This is the example of the modulation. Suppose our bit stream is 0 0 11 0 1 0 0 0 1 0. So, we are representing it and this format here and suppose we want to apply amplitude shift keying how to we apply this? Whenever our signal is given by once we have a data there, whenever is our signal is given by a 0 we do not have any data there. So, it is easy to detect it is locker system it changes the aptitude with each symbol.

(Refer Slide Time: 14:37)

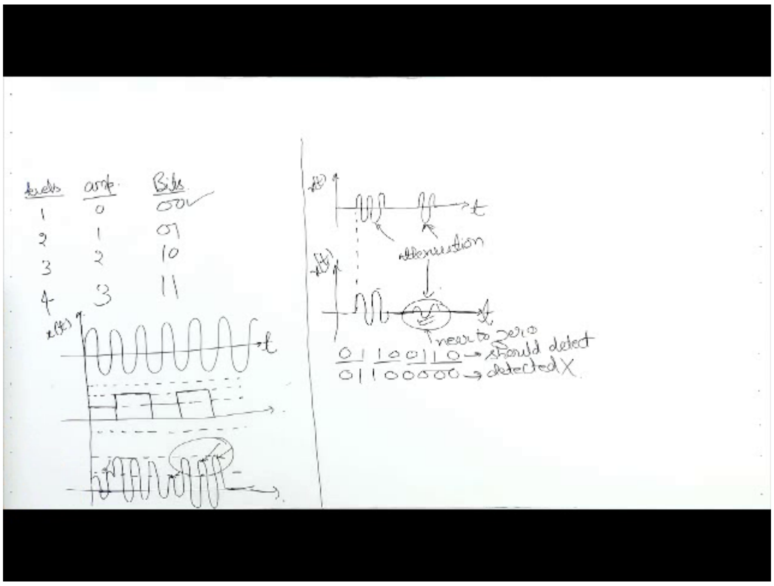


It is changing only amplitude. So, the frequency is constant. Because frequency is constant, bandwidths is 6 for that frequency and our bandwidth requirements are quite low. Now it is also susceptible to interference. Why is that? Now this is your incoming signal there right. In which is time and it is xt. So, either you do not have a signal or you have signal with the fixed frequency something like this. So, the detection happen based on the attitude suppose there is attenuation at a particular instance.

Suppose, let us say, and assistant suddenly it encountered can countered attenuation because of the multipath what will happen, that it will look like this to your receiver. So, in this duration it is finding something and here suddenly it encountered attenuation. So, it became very small it is possible that you are (Refer Time: 14:40) detector which is basically detecting the amplitude will mistakenly think that it is near to 0 and it will not detect this portion and what will happen, instead of reading 0 11 0 0 1 1 0 it will detect should detect this and what it detects is actually 0 11 0 0 and it also it detects as ok, which is wrong.

So, more susceptible to interference now we can do one more thing, if this example was only for 2 level aptitude means you have only 0 and 1s. So, it means whenever you have 1s you have just one amplitude if it is 0 it is simply is 0, but you can have even more levels. So, when we are talking about 4 level ask we will have 4 levels.

(Refer Slide Time: 14:08)



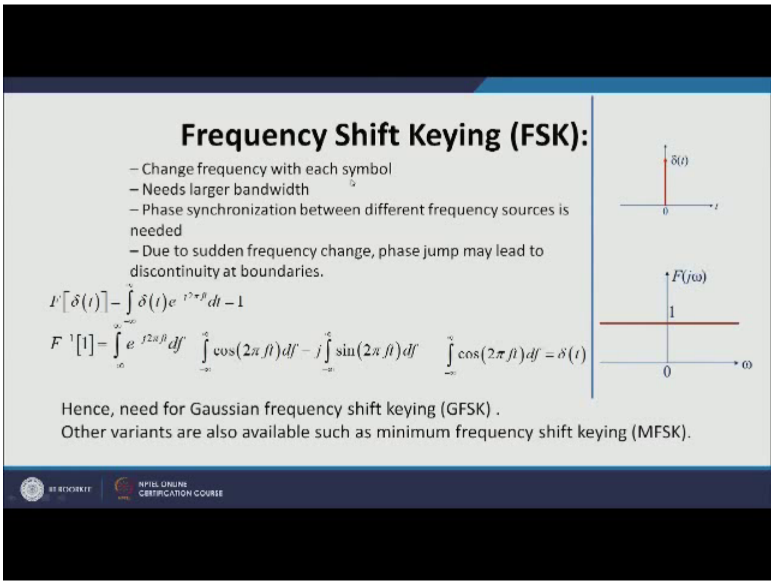
So, levels will be 1 2 3 and 4 and amplitude which will be representing them will be 0 1 2 3. So, basically in the bits form they will be seen as 0 0 0 1 1 0 and 1 1. So, what will happen in this case for example, in this example it is our carrier signal and our amplitude level are given by 4 factors there. So, for example, we want to represent 0 1. So, 0 1 is represented as 1. So, we have 4 amplitude levels 1 2 3 and 4. So, we have 4 levels.

Now, we will see our information from here. This is what you want to read detect right and we have taken 4 levels. So, we a we can have 2 bits at a time. So, 0 1 which is the first level will it will be represented as this 1 then the next 1 is 1 0 which is 2. So, second level between represented as this one third is again 0 1. So, it will be this 1; then 1 0 something like this. So, if correspondingly we will see in the ask modulation. So, it will be a small magnitude here then, little bit more bigger altitude here and from here it will be small again, from here it will be again big right. So, it will be and by chance this information has only 2 states 0 1 and 1 0 if it has there is possibility of 2 more state which is this 1 and 0es here right. So, it is 4 level.

Now, what is the problem here, detection is even more difficult here because, we have 4 levels and if any multipath comes into picture than if will impact this portion, this portion can easily can be mistaken for this path. Similarly, if this is facing the attenuation, the smaller amplitude it can go near 0 and it can be mistaken for this form. So, we will have wrong representation of the bits.

So, we can go to the high level ask, but that will be will be giving us wrong results. So, that is why, we move to other techniques. Next is frequency shift keying. So, we can see from here they are 2 frequencies whenever we have 0s here we have a smaller frequency here. Whenever we have once we have higher frequency here and for each 0 we can see the broadening of the pulse which is representing the lower frequency. So, it is the frequency shift key.

(Refer Slide Time: 20:47)

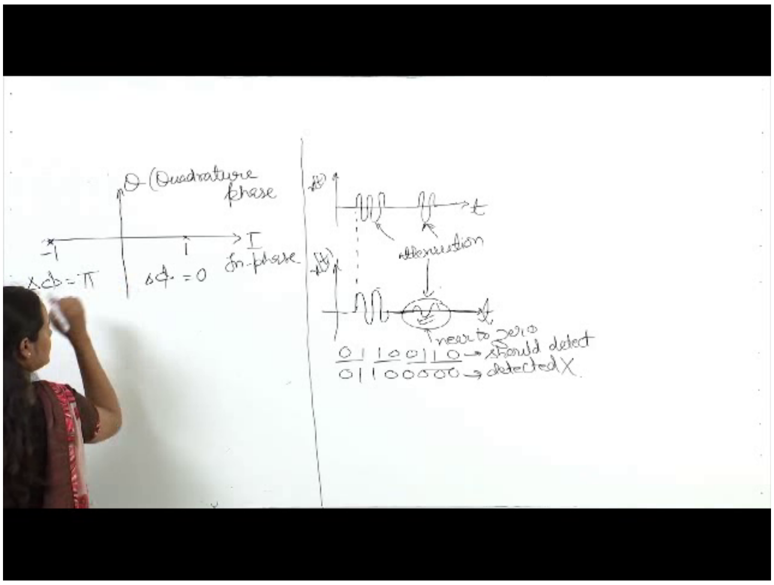


Now, what are the main features of their change in frequency with the each symbol because we are using 2 frequencies here. So, for sure it will be requiring larger bandwidth because we have to cover both the frequency. Now, frequency we are changing, but we have to be show that phase is not change their phase synchronization should be there between different frequency sources. Moreover, whenever there is sudden frequency change then there might be a phase change.

So, as a look here whenever there is a jump there, any discontinuities there the discontinuity can be represented as a data function or impulse function. So, this is what are seeing here impulse function. The FFT in the frequency domain that impulse function is given by constant 1 for all the frequencies so, this is the formulation when we are converting it from the time domain to frequency domain. When you try to convert it back to frequency domain and solve it for other modulation techniques.

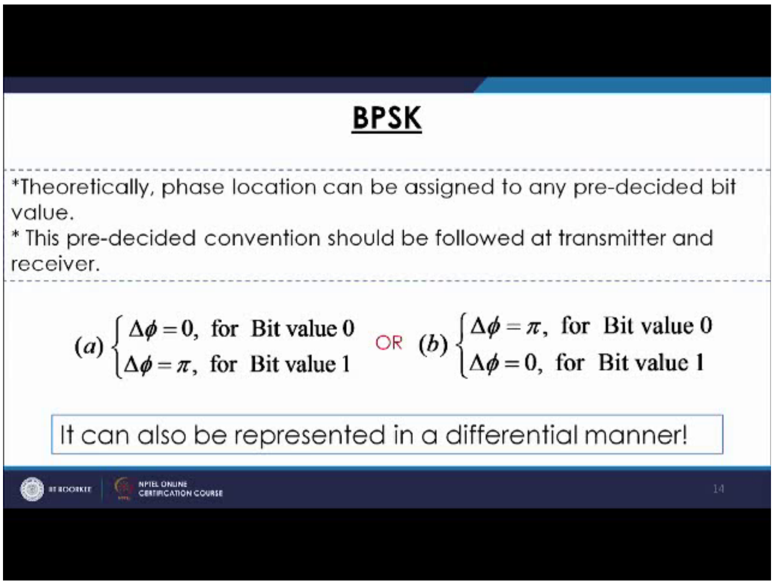
We can see that it is a combination of all the frequencies cosine terms we can see here. So, basically whenever there is a jump in a time domain, it will lead to the much distortion in the frequency domain at very wide band range. So, we do not want it. So, the because of this we have Gaussian frequency shift keying kind of frequency shift keying is key like FF GFSK and there are there variations also we are not coming those they are covered in digital communication courses mostly, but we want to have a background of this technique now the third one is phase shift keying. So, initially the amplitude we are changing the amplitude in frequency were wearing the frequency as name suggest we will be changing the phase in this is scheme. So, whenever you have a 0 we are having a change of 180 degree and whenever there is a one we are keeping it constant for that was also they are 2 phases there. So, this phase shift keying basically can be represented in terms of constellation diagram.

(Refer Slide Time: 23:17)



So, constellation diagram basically has a in phase and a quadrature phase. So, when we say binary phase shift keying, we do not have at the magnitude there only phase is changing there. So, it has only 2 conditions. So, 1 and minus 1 it just takes 2 values. What do you mean by 1? Whenever it is 1, it has phase shift of 0 degree and whenever it is minus 1 it is phase shift of pi.

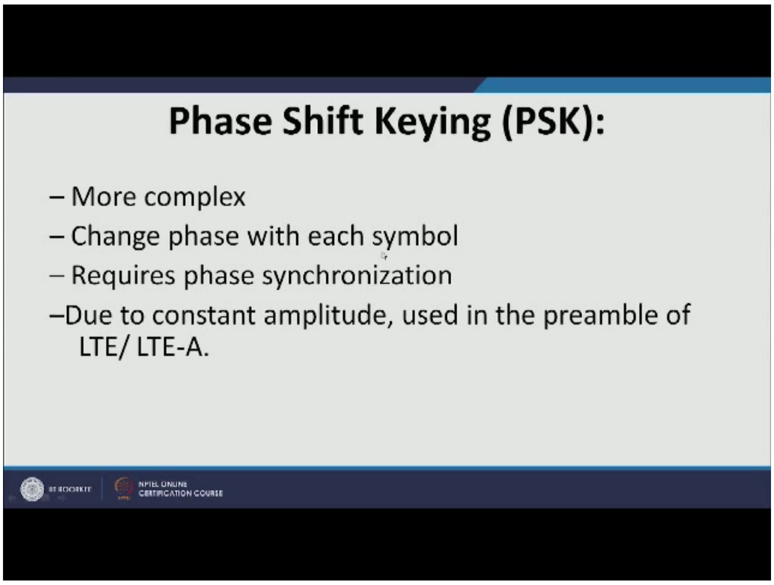
(Refer Slide Time: 24:11)



Theoretically a phase location can be assigned to any pre-decided bit value. So, this pre-decided convention should be followed at transmitter as well as receiver then it should be able to decode it properly. So, basically we can see here we can choose this shift in phase to be equal to 0 and it will be present bits value of 0 or we can choose it pi and it will be for the bit value 1 alternatively we can choose del phi is equal to 5 for bit value 0 and phase change of 0 for bit value of 1 as long as the same convention is used for both the transmitter and the receiver we are good. So, apart from this normal BPSK scheme it can also be represented in a differential manner which is called d BPSK. So, if you look at this diagram, this is what is happening. As long as there is 0 the phase is not changing, whenever a new variation in the width bit concern then it changes.

So, for example, after 0es we are having 1s and then we are having 1s then we see this shift in phase and it keeps going we are not changing with the both the 1s instead. Whenever we encounter a new change, means bit is changing from 1s to 0 then, we have this reversal here and when this 0 to 1 is happening then we have another reversal otherwise whenever we have same bits we are not changing the phase. So, it is called differential phase shift is it is more efficient because we are not changing the phase often as long as bits are same, we are keeping them same otherwise for each one we have to apply plus 20 2 degree and for each 0 we have to keep it same. So, this is more efficient. So, PSK is more complex.

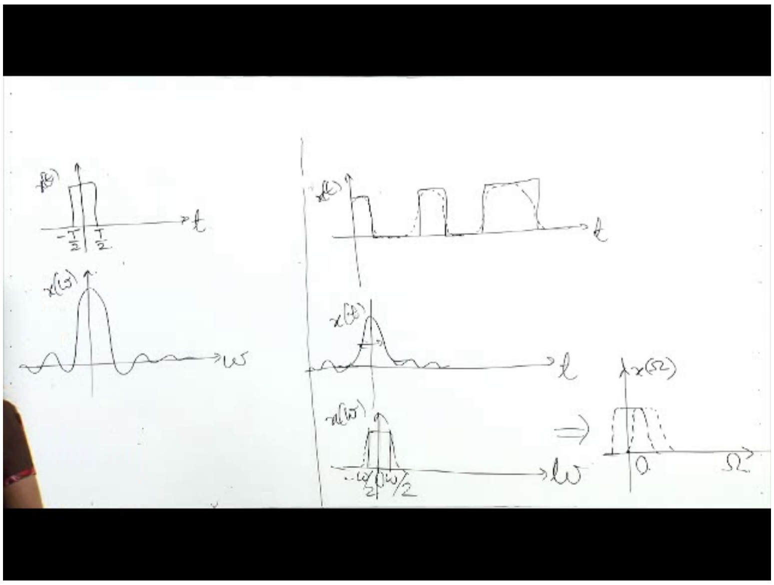
(Refer Slide Time: 26:10)



Especially when we go to higher level, there is the change phasing the with these symbol we need phase synchronization. Otherwise, it is very difficult to recognize where the phase have we started and we will read it as a wrong phase. Now, because you are changing things in phase we have a constant aptitude and because you have constant amplitude we mostly use it in the preamble of LTE and LT advanced kind of signal which are the basics for the 3G and 4G signals.

Now, why do we need this constant amplitude? We will cover later because we are going to cover the analog portion of the radio there we will see that we have a novelty in our transmitter path and when this nonlinearity comes with the varying amplitude signal then it the distortion occurs. When you have constant amplitude, there is no distortion. There is only attenuation according to the, that range of the power amplifier. So, we will cover it later. So, basically phase shift keying their; it is used for the higher order modulation techniques also now the next is the pulse shaping. So, whenever you have a pulse shaping, then you will you can contain the information in an error bandwidth. So, we require it why is that.

(Refer Slide Time: 27:33)



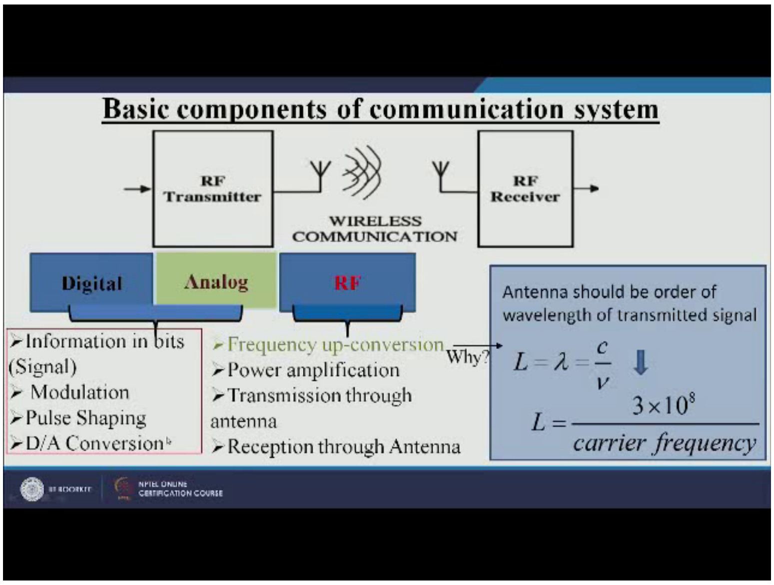
Whenever we have a pulse signal, in the time domain, you have a pulse signal, if you take the frequency domain transmission of this one and plot it in the frequency domain, you will find that it gives a same function. So, why we are pulse is contained from minus 3 by 2 to t by 2 here, this is the pulse width t you have.

Its frequency domain transformers actually you know, going through plus and minus frequency and it is much broadband then what you want to send. So, we need to have a frequency shaping because our inputs are what they are bits basically right. So, even after modulation mapping, this is something what you are sending right 1 0 0 1 0 0 111 something like this. So, as you can see here, this bits, they have this triangular form and then they will be converted back into frequency domain and we want to transmit in the analogue domain there, then you will find that they are quite broadband and they take lots of a space.

So, we do the pulse shaping. Now, if our pulse in time domain is looking like same function, then it is frequency domain is actually coming out to be a pulse which is a content form. So, basically this one will be contained in minus omega 2 by omega 2. That omega will be defined by the width of this route k cosine function.

So, what we try to do whatever is our input it does not look like this actually, we do little bit shaping here. So, it looks something like this. It is not a square any more. It becomes more continuous and then it is it is contains mostly in a particular bandwidth not is contained within a bandwidth. So, we can transmit it easily to the higher frequency.

(Refer Slide Time: 30:14).



After that we have D to A conversion. Whenever you as signal it is in digital domain, you have done the shaping. Now, your signal is ready to be transmitted and it is band limited within a particular bandwidth. Now, you want to transmit it. Now to transmit it, you have to send convert it into a analogue domain.

So, this portion which we have covered till now, it contains it is a digital domain, it has a information bits, then you have a performed modulation, you have done the pulse shaping and then after that, once we are signals contained, you are going to do digital to analogue conversion. Now it is in analogue domain. Now once it is in analogue domain it was signal was contained at 0 frequencies basically. It was the shaping in the frequency domain, but the middle point of the frequency the carrier frequency was 0.

Now, once we have conducting it analogue domain you get the same thing and now you are in analogue domain and you will have same signal, after D to A conversion in x rho analogue domain. Now, if you have a small digital, if it might be shifted to that new frequency or it might remain at the 0 frequency. So, till this portion we have converted from digital to analog. In the next lecture we will covering the analogue to RF conversion and the basic requirement of this system.