# Communication Engineering

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## Lecture – 2
## Communication Channel

Our topic for today's discussion is communication channels; basically it is a continuation of my discussion yesterday. In the previous class, where we looked at the block diagram of a communication system we identified four major things in there, there is an information source, we discussed the characteristics of the information source; there is a transmitter, the communication channel and receiver. We looked at the functions of all of these things, today I like to speak a little more, on the communication channel.

If you remember, I did mention something about, communication channel as a medium, to be thought of as a medium, and the communication channel as also an abstraction to model, all the effects, that take place in a communication system or most of the effects that take place in a communication system. So, I like to talk about both these aspects a little more in detail today, for some of the communication channels, now what we first talk about the effects that they model.

So, when I draw a box, say a channel, a communication channel, we are also representing, the various effects that happen to the signal, that take place on a signal. Whether, it is distortions or whether is noise additions that happen, anywhere along the communication system, the effect may not even happen in the channel, the effect will not actually, happen in the channel itself, physical medium itself. It may happen in the transmitter, the effect may occur in the receiver, but we blame the channel for everything.

We put the effect in the channel, and therefore, it represents all the bad things or good things that might be happening to the signal, and put it in a box called channel. For example, noise addition, when you are talking about addition of noise, actually noise is a very important issue in communications. Because there are a lot of sources of noise, in a communication system, the sources of noise exist, both in components of the transmitter, as well as components at the receiver.

Of course, some noise also gets along the way in a physical medium, but not all the noise is added, in the transmission. Lot of it happens, at transmitter and receiver, particularly at the receiver, the noise level at the receiver is particularly very, very important and significant. But, still we, put the effect in the channel, so channel in everything that we cannot, put either at the transmitter or at the receiver directly, so that is an abstraction, so please remember that.

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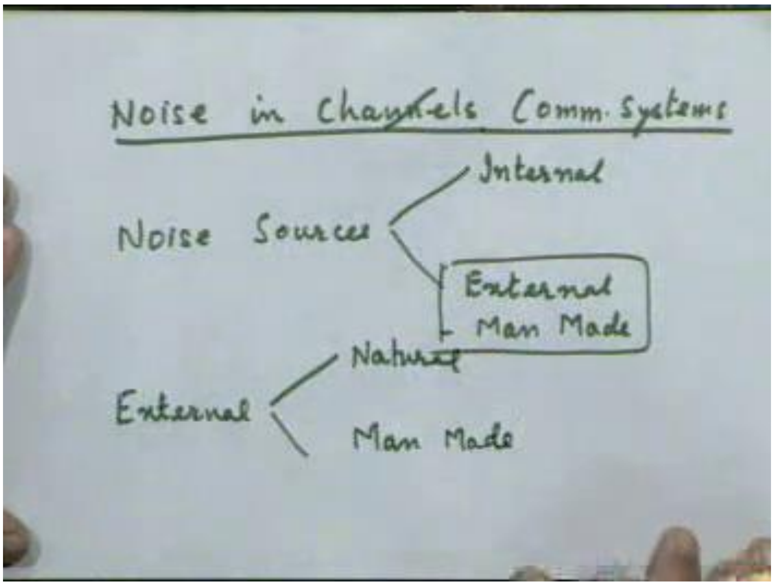


To start with let me discuss, the channel characteristics in terms of noise, so noise, types of noise that we encountered in channels. So when I say noise in channels, again this imply that noise in communication systems may be. Channel is just a, we have to present in those effects. There are two kinds of noise sources that, we have in communication systems. I should really say noise in communication systems, more precisely and there are two kinds of noise sources, that we can have and we can categorize them, as being either internal noise sources internal means, internal to the commutation system.

Somewhere, in a communication system there is a noise source, and therefore, it is internal to the system, it is not coming from outside the system; that is, one kind of noise, it may be transmitter or receiver or a physical path. The other are, what we call external noise sources, the external noise sources are typically, what we also can say manmade noise sources, sources arising out of some activities of mankind, that is something is happening in the neighborhood, which creates some noise or interference. For a communication signal, so that becomes an external noise source or a man made noise source.

Now, let me first take these external ones, external sources, I must slightly modify my statement not all external sources need be manmade. It can be external noise sources, which are natural, so actually, speaking I should have said, that the external noise sources are also of two types, one is natural and manmade.

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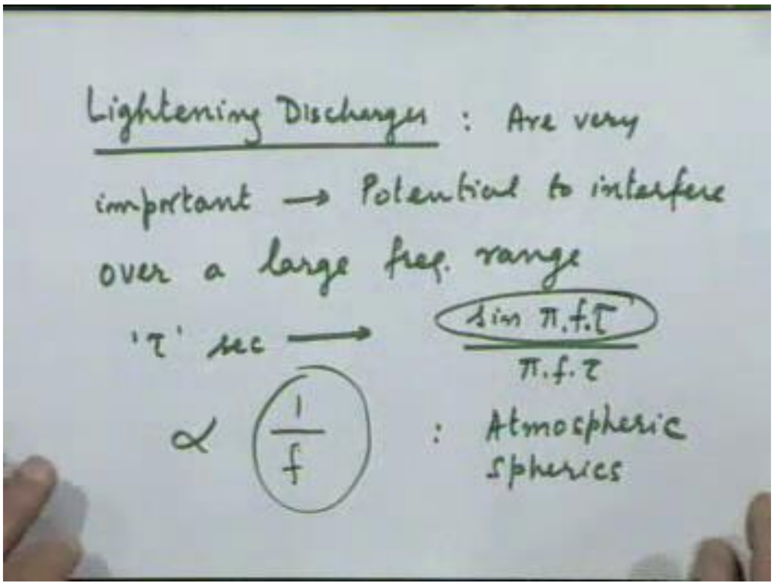


Let us talk about the natural sources first one of the biggest natural external noise source is correct, somebody is saying lightening discharges, when lightening discharge takes place, a large amount of electromagnetic radiation takes place, and what is lightening, it is a very narrow burst of large energy. It is an impulse kind of signal, if you look at it from a signal point of view it is an impulse kind of a waveform, a very large amplitude waveform. Hence obviously, electromagnetic in nature, and therefore, it will have what kind of spectrum does an impulse ideal impulse have.

Student: ((Refer Time: 07:37))

Constant the Fourier transfer of impulse is a constant function, so it is spectrum is very wide and therefore, it has a potential to interfere, where a very large frequency is it clear. So, lightening discharges are very important from this point of view, because have the potential to interfere over a large frequency range, actually the spectral characteristics of these discharges, this noise source is exactly a constant, because after all already we are saving it in impulse, actually it is a pulse of some finite duration. The division may be very small, but it is still finite and what is a spectrum of a pulse, of any duration, what is the nature of the spectrum.

Student: ((Refer Time: 08:49))

Same function, sine x by x sine of function, so if it is for example, if this lightening discharged is of duration tau seconds, what will be the nature of this spectrum. So, the first is tau seconds, the spectrum would have, the nature of sine pi f tau upon pi f tau, now this is always between plus minus 1, so as a function of frequency, now what is the characteristic 1 by f.

So that means, actually speaking 1 by noise, sorry the lightening discharged noise, it is also called sometimes these are called atmospherics, this kind of noise is also called atmospheric noise, or simply for short we call them spherics. So, this atmospheric noise, due to lightening discharges, actually has a spectrum, which decays with frequency, so it is really more important, that low frequencies, higher frequencies. Now, lower and higher is in relation to the, various bands that I was talking about yesterday.

So, if you carrying out communication, let us say in the medium frequency band or the h f band or the, may be the v h f band, this may be significant. But, as you go higher and higher in frequency, the effect of this noise will be smaller and smaller, I have to be particularly very, very important at low frequencies. For example, if you are doing communication at v l f, sometimes you do communication with v l f, for very strategic applications, or at mid level frequencies, this noise becomes, one of the major sources of disturbance for us to worry about. So, that is about the frequency spectral characteristics of atmospheric noise, in time domain, as I said these are characterized, this kind of noise is characterized by…

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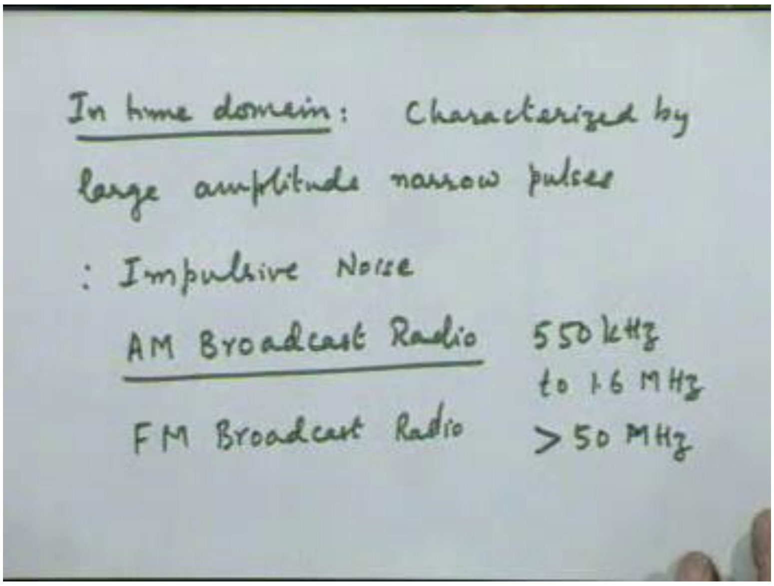


So, that is the spectral characteristics, in time domain, this kind of noise is characterized by, large amplitude would you like to complete the sentence, large amplitude, narrow pulses, and therefore it is also sometimes called impulsive noise. So, this is particularly important at low frequencies, let us say in the, AM broadcast radio anyone knows, what is the frequency band used for this application.

Student: ((Refer Time: 12:19))

Anyone can noise communication engineers, should know some of these things, in your finger tips,

Student: ((Refer Time: 12:25))

It is slightly higher this is of the order of 550 kilo hertz to about 1.6 megahertz. So, it is particularly important for this frequency band, because this is not a very high frequency band. It is actually called medium frequency band, medium wave in the standard terminology whereas, if you look at FM broadcast, do you know the range for this.

Student: ((Refer Time: 13:03))

It is greater than 50 megahertz correct, you are absolutely now, this is much higher than one megahertz. Becomes relatively, not so important, this is kind of noise, because it does not have the potential to disturb us, as much as it has, in this particular frequency band.

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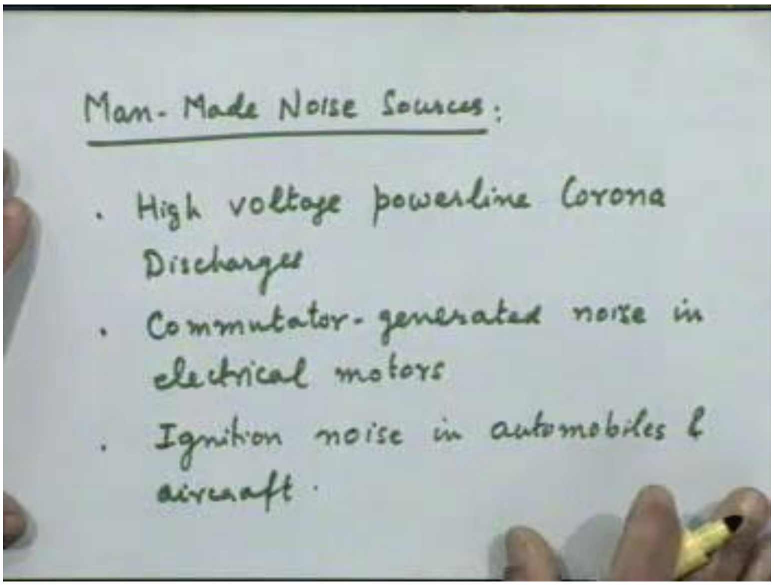


Now as, coming next to manmade noise sources, there are many, many sources for this, and mention a few of these here, you heard of effect in power, many of you are from power area. So, there is this, high voltage power line, what is called corona discharges, and we have the same kind of behavior that the lightening discharges have, it is like any other discharge. Then, if the law of electrical equipment, let us say, which is operating in my neighborhood, which contains let us say motors, or generators, electrical motors or electrical generators.

You know that these motors and generators have kind of switching going on all the time, is not it where, which part of the motor of the generator. The commutator, there is a on off, contact on off thing happening all the time, as there is a as a rotating part as an armature rotates. The contact between the armature and the outside world is through the brushes and the brushes operate through the commutator. The brushes and this is constantly, going through a process on off, as the armature rotates and therefore, that creates switching, and that again creates a kind of an impulsive noise.

So, we call this commutator generated noise, in electrical motors, similarly, in the automobile or the aircraft, if you are carrying out communication there, their sources of noise there, which are because of the machinery. Can you think of some, the aircraft or the automobile ignition noise, what are you doing, ignition means, what are you doing. You are creating a spark, momentary spark, in every cycle of the, in every cycle, this is, there is a time during, which a spark is generated and of course, the source of radiation, and a source of electromagnetic noise for us.

So ignition noise, in let us say automobiles and aircraft. Anything else, you can think of, in the telephonic exchange, what happens in the telephone exchange, lot of switching takes place, you are connecting users, as we dial the number, there is a lot of mechanicals. Of course, age of mechanicals, which is now over, but still, there are electrical switches. So, you have to create a path between the, person who wants to talk and to the person, he has dialed and that, creation of that path has to do lot of switching.

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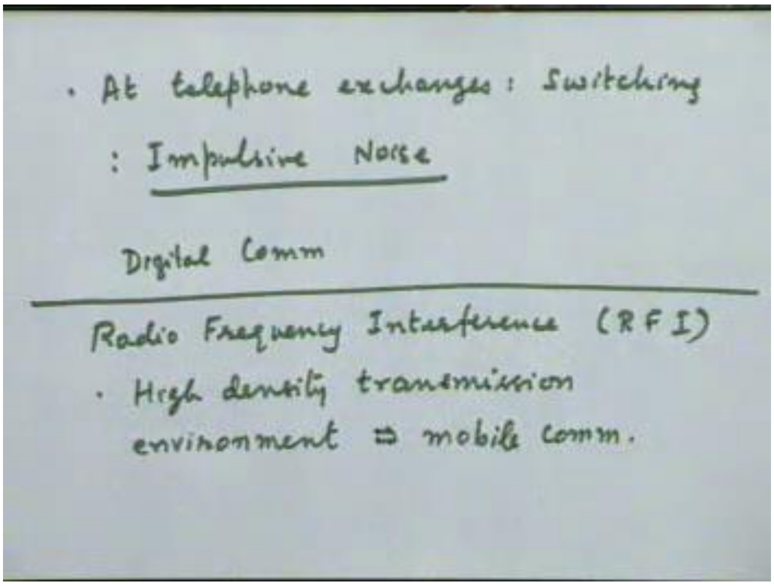


So again, at let us say electronic exchanges or at telephone exchanges, there is a lot of switching. So, any place, where there is a lot of electrical switching taking place, it is a source of radiation for us. Please remember that, and a source of typically, what we call impulsive noise, have you heard of this. And, what attribute one effect of impulsive noises, let us look at it little differently for two kinds of situations, if you are actually carrying out wires communication or analog communication, impulsive noises at best at, and best an irritation.

If you have heard of, if you try to listen to short wave radio or AM radio, sometimes when lightening takes place, you do hear a lot disturbing kind of sounds. So, it is an irritation, but you can still make out, what is happening, what is being said, and perhaps of the song that, you are listening into is still intact. But, when you are communicating data through the channel, this can be fatal to the data, because due to the occurrence of the impulse and sometime around it, the impulse, the amplitude of this signal is, so much larger, than the signal amplitude, that it will overtake the receiver.

And, what you will finally, get in the output will have absolutely no resemblance to the data that you actually transfer, so you totally kill the data that you actually transferred. So, impulsive noise is something that we particularly worry about, in digital communication, not that it, is not important for analog communication. But it is something very, very crucial to worry about in digital communication. Because, data would be entirely lost, in the interval, in which this large amplitude pulse interference takes place, it is obvious, I do not think, I have to explain that too much all.

Any questions, ((Refer Time: 20:02)) still with the manmade noise sources. But in this case, the man made noise sources are, not due to the other activities of mankind, but due to communication activities of mankind. So, there is the so called radio frequency interference that we must talk about, which is usually denoted by RFI, and this is due to the fact, that you are not the only one, who is communicating. Now, this is particularly important, when you are doing communication from free space, using radio waves.

You are not the only one who is communicating, there are lots of people, who particularly today; in today’s scenario, in today’s wireless communication scenario, this is a kind of interference, which has becomes suddenly, so important to worry about, it was never, it never was earlier. Why, because of the fact that there are, so many mobile users, and every mobile user is operating at a certain frequency, typically in a small living hood, all operate at different frequencies.

All use the same frequency, at different time slots or whatever, but still, this is such a large number of these users, there is bound to be interference, if not within the cell, just nearby cell or couple of cells away. So, radio frequency interference is today very important, in view of the fact, that there is very high density transmission environment. Particularly in the context of mobile communication in a big city, due to mobile communication, but it can exist even otherwise, because there are so many things communication activities are happening.

There are the aircrafts, which have been guided, to land at the airstrip, so there are transmissions taking place, because of that, there is broadcasting activity that is taking place there is satellite communication that is taking place, of various kinds. The radar systems which are operating in the neighborhood to track either your friendly to unfriendly aero planes. So many communication activities are taking place all the time, and every communication activity, is a source of interference to every other theoretically, unless they are highly removed from each other, in the frequency domain.

If they are close by, there is a potential for interference, all these we call radio frequency interference. Now, although I have gone from, natural external sources to manmade external sources, if we combine briefly to natural noise sources in nature, and now these are natural sources, which come from outside our terrestrial world.

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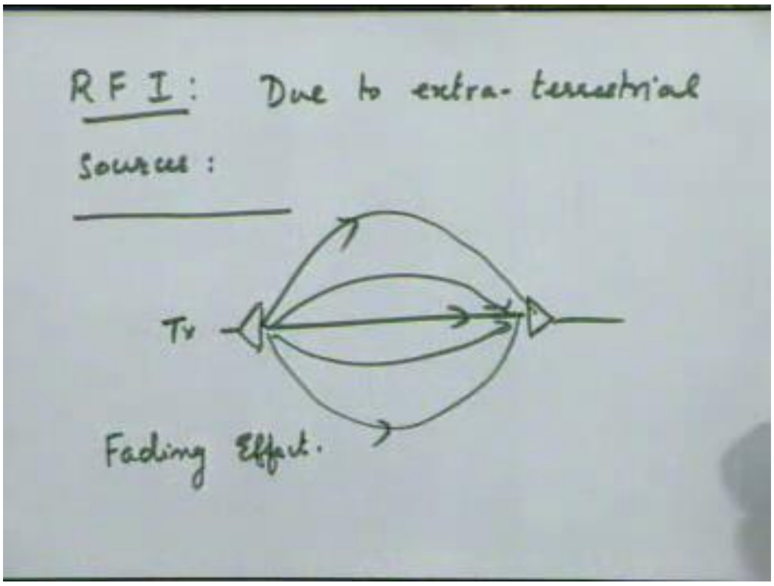


The natural radio frequency interference, I am on the subject of RFI now, this radio frequency interference need not come only from other communication equipment, on the globe. You can have radio frequency interference from, outside the globe, for example, you know sun, is the major source of everything to us, all kinds of energy and amongst this all kinds of energy, there is a lot of electromagnetic energy, in the form of radio waves.

Most of the time, when I look at, when we talk about sun energy we talk about the light energy and the ultra violet, and the infra red. But, the infra red, if you go lowdown, basically radio waves, so one has to keep that in mind, and of course, if a new optical free space communication, then directly a problem. So basically, stars light our sun and other stars, because even though, the stars are very far away from us, each of them is a sum.

Each of them is a source of radiation, it looks as if it will be very small, but the collective effect ofso many stars in the universe is not so small, particularly, when you are working with very, very weak signals. All this noise, background noise, due to the extra terrestrial sources, again becomes significant of course, as I would, said one man's food is another man's poison. What we consider noise is a very important signal, for somebody else, who?

Student: ((Refer Time: 25:27))

The radio astronomers, they are looking for those weak signals and trying to understand the objects, and we here ((Refer Time: 25:37)) lot of interference for them to, so it is exactly like this. For us, that is a source of noise, for them what we do here is a source of interference in their work, because they cannot observe these effects properly. And there is a lot of tussle between the radio astronomers and the communication engineers, in getting the bands allocated.

For example, we have a, have you heard of the giant radio telescope in India, in Pune and in Ooty. And they work in a frequency band, and that frequency band is being endangered, by the communication activities, that are taking place now, so there is a lot of tussle, that is going on in these issues. So, radio frequency interference, due to extra terrestrial sources, we have to, we have heard of and ((Refer Time: 26:39)), they are basically, radio frequency information that astronomers are dependent on.

The sources of interference for us and a source of information for them, the interference source is an information source for somebody else. What are down with external noise sources yet, I think, I am coming back to internal now, we talked about this radio frequency interference, from various places internal and external. But let us think about a situation, where you own communication activity, can generate interference for you, can that happen. Can you imagine the situation where, the signals that you have transmitted can also be a source of problem for the receiver in a, particular situation. Can you imagine any situation where…

Student: ((Refer Time: 27:52))

Feedback from where?

Student: ((Refer Time: 28:06))

But, where does that feedback come from?

Student: ((Refer Time: 28:13))

From an echo, have a reflection from somewhere, basically what is happening is, but the analogy is absolutely correct, so I will give full marks for that. So, issue is you have a transmitter, you have a receiver, ideally there, should be a single path of propagation, between the transmitter and the receiver, that's the problem. So, there is a transmitter, this is your transmitting antenna and this is your receiving antenna, there is a single path of between these two, no problem.

But, if let us say, for various reasons, the multiple paths, that exist between the transmitter and the receiver, so the radio energy, not only goes from directly, but may be through some other indirect paths. Now, the receiver is confused, it does not know which one is the signal, to look at, so and what is known, remember the delays of these paths, this symbol here, may be weak or strong. Suppose, you take a sine wave and delay it the different phases, and add you are adding the same frequency sine wave in different phases.

Depending on the relative phases of this, very sine waves, of the same frequency, the net amplitude of the resultant sine wave may be either small or large. They will reinforce each other, or destructive interference for each other, so you might have, you might get, what is called it also happens that this multi path environment is not fixed with time, it keep changing with time. It can happen that sometimes, you get a constructive interference, and sometimes you get a destructive interference.

So, signal is strong sometimes and signal is weak sometimes, this is what is called the fading effect, due to multi path propagation. So, signal fading takes place now, because of this interference, and that is very, very irritating for, in analog communication a very, very destructive to data in data communication. This is typically, what will happen, let us say in mobile communication, because between the base station and your handset, there are multiple paths, it is not a single path. Why? Because the base station transmission is not pointed towards the handset, it is generate broadcast.

Once you generate broadcast, you will get, a direct signal from the base station to you, but also in the signals, which are reflected by buildings, by trees and other kinds of sources. And, if in addition if we also move it, these various parts, they will keep changing with time, the actual paths will have to remain fixed and you will actually, theoretically be able to see the effect of fading.

However, your handset is, so nicely designed, that it does not allow the fading effect to come through to you. But, that is a very good, very important signal processing channel for communication engineers, to make sure the fading effect does not finally, reflect all the thing that you hear. All the data or sms information or the internet information, that you are transmitting through a mobile, so that is, one of the great challenges and a very important area of research, even today.

So far, for the internal and external sorry, natural and manmade noise, sources from outside the communication system. Remember, we said noise sources could be internal to the communication system or external to the communication system.

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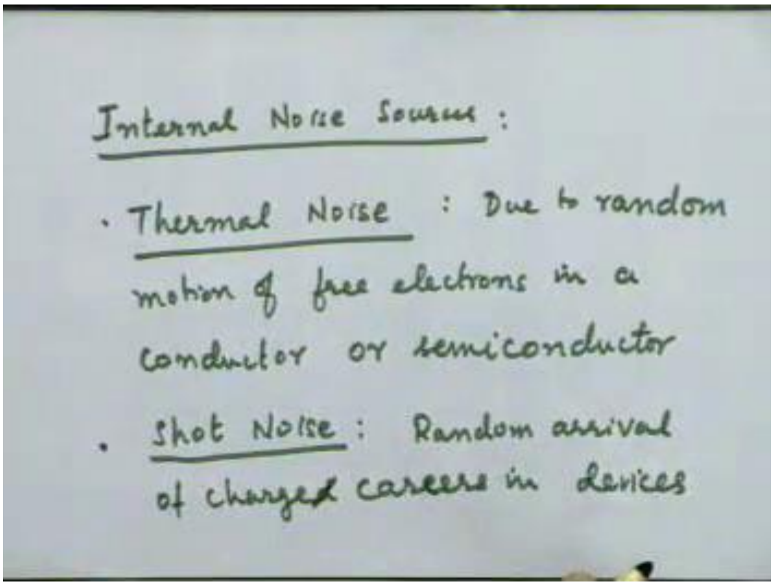


Now, let us return to noise sources, internal to the communication system, the two most important internal noise sources, are remember the definition of internal noise sources, the noises, which are being generated within, the components of the communication systems. Where will they be generated, anyone would like to make a comment, where does noise, get generated.

Student: ((Refer Time: 33:07))

No precisely what is the mechanism, would you like to say anything?

Student: ((Refer Time: 33:16))

No, I thought perhaps you have, you read about electrical current, what is the nature of electrical current, is it very nice smooth flow of electrons, that takes place or is it something different.

Student: ((Refer Time: 33:38))

Basically, electrons are always in a random motion and the current takes, when there is no voltage and no current flows, this random motion still exists. When you apply a voltage and the current takes place in the conductor, current starts to flow in the conductor, what happens is this random motion drifts to one side. So, there is always, this random motion of electrons due to thermal energy that they contain, depending on the temperature at which they are operating, the conductor is captured.

So, this is the first most important source of noise, which is therefore, present in every electrical component of a system. Wherever, there is a current flow of, even if there is no current flow, there will be thermal noise, so the first kind of noise internal noise is what we call thermal noise. There is a well known formula for this, how much noise you will see we will discuss those formulas later, it depends on the temperature, at which the component is operating.

So, if you have a particular ((Refer Time: 34:55)), so you have resistors in your circuits you have transistors, you have diodes you have all kinds of electrical components, electronic components. Everyone, one of these components generates thermal noise and since, you can have hundreds of thousands of these components in a system, no overall effect of this noise would be significant, it will not be insignificant, so this is one kind of internal noise. So, this is due to random motion of free electrons, of course, it should be it is random motion of free electrons, not all electrons in a conductor or semi conductor.

The second kind of noise is called shot noise, I do not know whether, you have read something about the, you have gone through some sources, where you learnt about the transistors and diodes. And perhaps, in some context also some vacuum tubes, in some context may be not. But in all this, so called active devices, we have charged carriers, you know that, you have the for example, in a semi conductor, you work with electrons and holes, the charged carriers.

Now, and typically they propagate from, let us say one point to another point, let us say they are from, the p junction to the n, p type of the material to the n type, and it goes from one junction to another junction. And again, this charged carriers, now we are not talking of only electron motion, we are talking of any kind of charged carrier that you might have. The arrival of each any one of them, or a, this charged carrier at a particular point, will be totally random again, so that kind of randomness, also generates shot noise.

So, basically this is due to random, what we call random arrival of charged carriers, I am not going to detailed physics at this limit, maybe we will have time to discuss this separately later. Then, arrival of charged careers, in various kinds of semi conductor devices, so you will have shot noise in transistors and in diodes and things like that, there are slightly different kinds of physical effects. And that is why, they have been given, different names and their mathematical models are also slightly different from each other. As to what these mathematical models are we will discuss them separately, so much about noise. I think I have made a lot of noise about noise, and that is because, noise is very important in communication systems.

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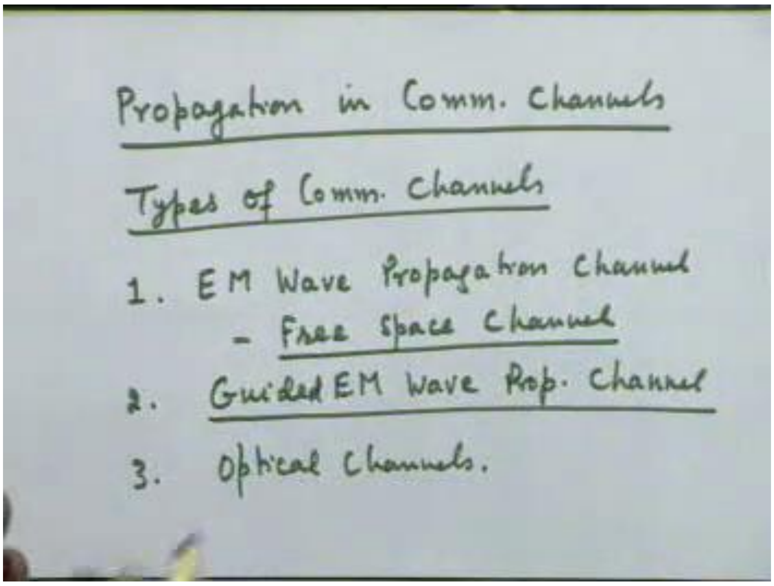


Now, the last thing I like to, discuss in the context of communication channels, is something about, let us say, propagation in a communication channel. That is, looking at the medium, looking at the communication channel from the point of view of, how the electromagnetic wave actually propagates, so I am looking at, types of communication channels from this point of view. Again, remember my original point that I made some time ago, that we are talking about electrical communication, which happens, because of transmission of electromagnetic energy.

That electromagnetic energy neatly carried in a pair of wires, through a cable or through free space or through fibers. ((Refer time: 39:49))So, one of these you look at, you can characterize all these communication channels, form the point of view of propagation also. How the energy actually, propagates in these various media, now what do I mean by that, primarily, you can talk about three types of channels, from this point of view and these are as follows.

One we call simply the EM wave propagation channel, for want of a better name, but perhaps you could also call it, free space channel. The second one is, guide EM wave, propagation channel and the third one, or really a subset of in the second one, but it is still worth having a third kind called the optical channels. So ((Refer Time: 41:10)) it appears, as if it is just ((Refer Time: 41:12)), but there is an important difference here, between one, two and three particularly between one and two. Free space propagation, cannot occur on globe on the earth, can you say why, does this statement make sense to,

Student: ((Refer Time: 41:37))

Because, we are there is no free space here, we are living on earth, so where is the free space. The atmosphere looks like free space to us, but it is, adjunct it is adjacent to the earth, so there is a boundary here, there is one kind of medium, above the surface and another kind of medium, below the surface. So, truly speaking, anybody on earth, you cannot have true free space propagation, but you can have free space propagation, that is in space, far away from heavenly bodies, between two points.

Because, in free space propagation, that you might have learnt, the way the basically the through spherical wave fronts. Spherical wave fronts are simply not possible to support, in any in the, of any conductor or in, the of any object, which will disturb these wave fronts, and earth is very much approximated to every kind of situation, that you will work with here. So, free space channel really exists, only in true free space that isgoing space. Do you agree with that, but let us look at, approximately you can also have free space, in the neighborhood provided make sure, that you are more or less working above, somewhere.

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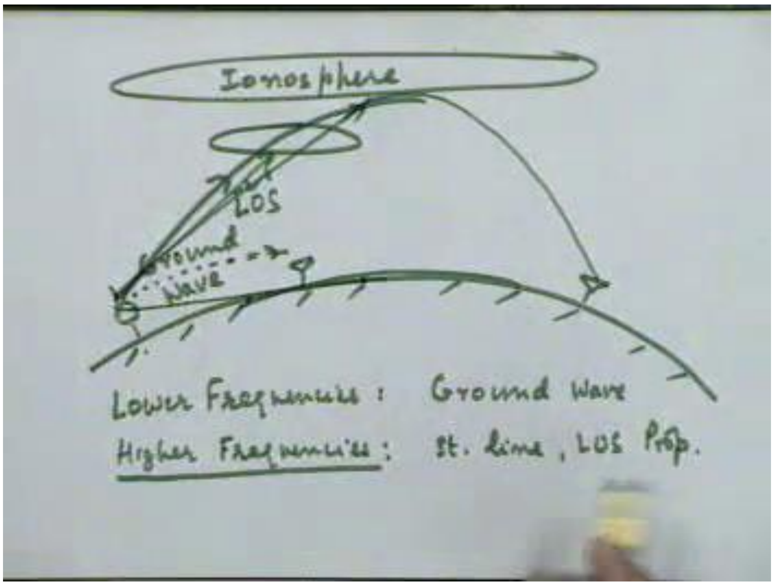


Now, I had this picture, but it was not coming very clearly, I have to try it here now, let us say, this represents the earth. This, curve represents the surface of the earth and let us say you have a transmitting antenna somewhere here, and some receiving antennas elsewhere. And, what are the various kinds of situations that are possible, in terms of the way the propagation will occur between transmitter and receiver.

One mode is, the way we propagate along the ground, for example from here to, from the transmitter to a nearby receiver, the actual propagation follows the propagation path actually, follows the curvature of the earth. It is, you have done a course in electromagnetic waves, EM theory, so you know, what happens when there is a medium, which is bounded on one side by a conductor, what kind of wave, get supported.

Student: ((Refer Time: 44:49))

There's some guided wave, so this ground wave is a guided wave in that sense, because it is guided by the, surface of the earth, so this is called the ground. So, this is a kind of guided wave, the conductor guides the wave, along it, along with it, then you can have a, something like a free space propagation or sometimes also called sky wave. If you are, just transmitting up, you are transmitting away from the surface of the earth, so for all practical purposes, it will look like more or less a free, space propagation and which will be typically, line of sight propagation.

For example, let us say when you are communicating between, from an earth station to an aero plan. So, let me just, draw the aero plane like that here, a very bad drawing, but some ((Refer time: 45:55)) communicating with the object situated, above the surface of the earth, or a ((Refer Time: 46:03))for example you are making a transmission to the ((Refer Time: 46:05)). Then there is a slight difference between these two, which I will talk about.

Now suppose, you want to communicate form here to here, it is a ground wave ground wave is good, but ground waves will be supported in a fairly narrow frequency band, typically lower frequency band, the medium frequency band. As you go up higher in frequencies, what will happen, this earth looks like ((Refer Time: 46:38)) also, you know also some problems, that is the, effect and attenuation and things like that.

Attenuation becomes, so strong, that high frequencies and the ground waves really, cannot be used as a propagation mode, for distance over, communication over large distances, because as you go up in frequencies, the attenuation increases significantly. So, ground wave is really, typically useful for lower frequencies or higher wavelengths, but if you have lower frequencies due to these quite nicely, when you go to higher frequencies, this is not very useful.

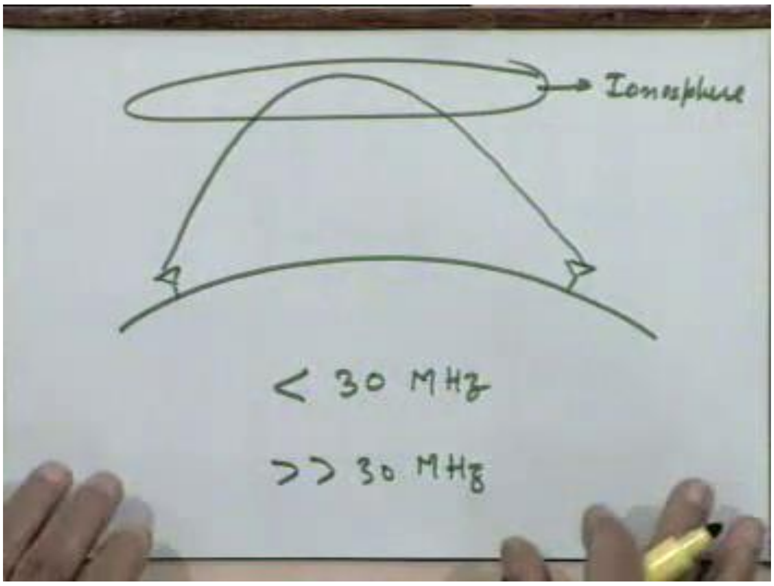
However, this kind of thing is possible, straight line propagation is possible like that, straight line propagation is also possible, let us say, if you have two high towers, on the surface of the earth and they can see each other. So, line of sight is possible, straight line propagation is possible, at a higher frequency, so we call straight line or L o s propagation is possible, now if you want to have, work at a higher frequency, there is then a limitation, as to how much distance you can communicate.

Because, the propagation will have to be a straight line propagation, in line of sight propagation and because of the earth's curvature there is a, certain distance beyond which, you will not see. Depending on the height of the when you can go up to here, but not beyond, there is a tangent here, so it will only go up to here, after that, the curve, this way will be obstructed by the surface itself. So, what do I do, if you want to carry out high frequency communication, between two largely, remote stations.

You will need somebody to come in now into picture, which will reflect the wave back, so you will transmit the wave up and can be reflected back, and there are two ways in, which it can be done. One is through a satellite and the second one is through an effect that is present above the surface of the earth, there is a layer of charged particles, somewhere a couple of kilometers, away a few kilometers above the surface of the earth, which is called the ionosphere, so you have the ionosphere here.

So, this acts a ((Refer Time: 49:41)), so if a wave is sent up, it will get bent like that, of course, it is a very imperfect drawing, typically, actual propagation path will look like this, let me draw another picture.

(Refer Slide Time: 50:03)




So, you have an antenna here, and an antenna here, you may have a path here like that, and that reflection. Of course, it is not a straight line propagation, because there is a refraction taking place at the atmosphere itself, and this reflection is due to the presence of the ionosphere. So, ionosphere is a very nice natural phenomenon, which helps us to carry out, long distance propagation, at higher frequencies, but how much higher, not for all high frequencies, it also has a limitation, the frequency must be less than about 30 megahertz or so, may be a little this way or that way, but around this range. If your frequencies are still higher than this, then you, say that you will transport around here, you skip the ionosphere, they will go out of the earth, they will, never come back.

Student: ((Refer Time: 51:08))

Sorry.

Student: ((Refer Time: 51:14))

That is why, we are sending it out.

Student: ((Refer Time: 51:23))

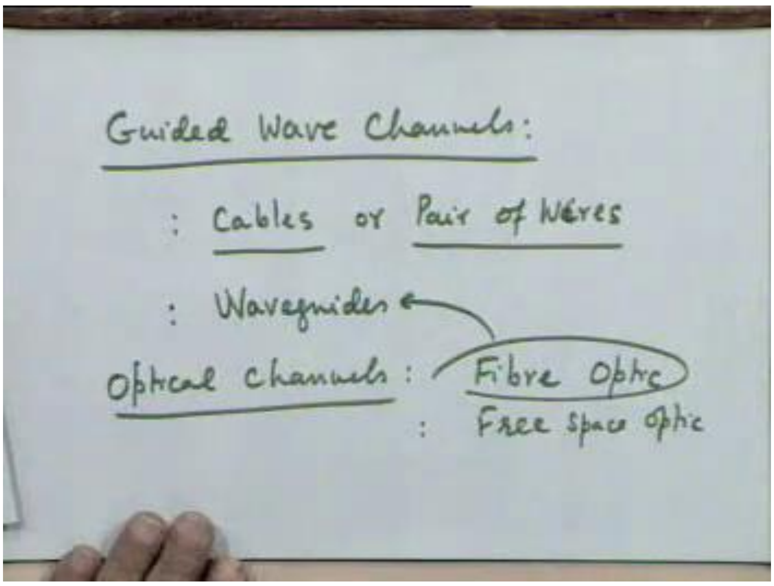
No attenuation is due to ground wave propagation, the ground wave, due to the high frequency, will attenuate very fast, but this will be, due to the of course, propagation loss will always take place. If you have standard propagation loss, the inverse square laws, as you go away from the source, the ((Refer Time:51:46)) will be proportional to 1 by r square, that will always be there, of course, that is ideally true only with, free space propagation.

This is not exactly free space, but roughly the same kind of thing, will take place, may be the power will vary from 1 by r square, it will be from 1 by r to the power 3 by 2, because this is not exactly free space. But, other than that attenuation, the attenuation that I was talking about along the ground wave was much more than this inverse square law. So, at a higher frequency that 30 megahertz or so, it will highly propagate to a few meters, along the ground, so you will not see, so you have to use other means.

So, but as I said, this mode propagation is also useful only below thirty megahertz or so, If you are trying to communicate a frequency, which is much greater than thirty megahertz, the ionosphere does not help us at all. And, ((Refer Time: 52:46)) the, is by having an active reflector or passive reflector, much above the surface of the earth. So that the wave can, go through that and then be reflected back by it or retransmitted back by it.

If it is reflected back, we call it a passive satellite if it is retransmitted back, it becomes an active satellite. So, I think, this gives you an overview of the first two kinds of ((Refer Time: 53:18)) really mostly the first kind, and the second kind, the guided wave propagation is partly ground wave propagation, that I talked about.

(Refer Slide Time: 53:32)



But most important more importantly amongst the guided wave propagation, you also have guided wave channels. You also, have every kind of communication that takes place through cables or pairs of wires, pair of wires. A cable, normally you look upon you r cable or a pair of wires, as if they are carrying current and talk about vertices and current. But, basically we are transmitting electromagnetic waves, depending on, whether you are working at the lower frequency or a higher frequency, you can treat them as circuit representations or otherwise you cannot represent them.

You have to work with them, in terms of EM wave propagation, if you, if they become transmission lines, we do not call them, just circuits anymore. A pair of wires may look like a circuit, but if you do so only at, lower frequencies of operations, where the size of the objects involved the wires and the components, is much smaller than the wave length. If your sign in the transmission line becomes much larger than the wavelength, then no longer, you can talk in terms of a, l m circuit mode.

You have to think of them, as a means of propagating electromagnetic energy, electromagnetic energy is being transferred, and the way you study, these same things then, is not to the same theory, but through transmission line theory. So, if you are working with cables or pairs of wires, all guided waves, wave guides for example, guided waves can also be wave guides, you know about waveguides, waveguides are essentially either cylindrical or rectangular, metal objects pipes, through which electric energy is transmitted.

For example, you can have an entrance upstairs, like we have here and there is a transmitter, electronic equipment sitting downstairs. How do we get the energy from there to here, inside, you typically use a waveguide, actually it is a pipe, literally it is a pipe, either, a cylindrical pipe or a rectangular pipe, so that is again guided waves. And of course, optical channels, you can have two kinds fiber optic or free space optic, you can have free space optic for communication or you can have fiber optic communication, but really speaking, the fiber optic communication is included as a wave guide.

If it is a cylindrical waveguide, in which it so happens that the cylinder is so thin and we are transferring light energy through it which is often electromagnetic energy, actual propagation mechanisms are exactly the same, so they can be treated like that. A free space optical communication is like free space electromagnetic energy, except that typically, unlike in that situation, you typically like to focus the energy, in a very narrow beam, so that it goes from point a, to point b effectively.

That is very commonly used in, free space probes that we send up, but it is also used for many terrestrial applications today. So, I think with this, I will conclude this, talk on communication channels.

Thank you very much.