**Introduction to Biomedical Imaging Systems**
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**Lecture - 49**
**MRI_slice sel_S27_S41**

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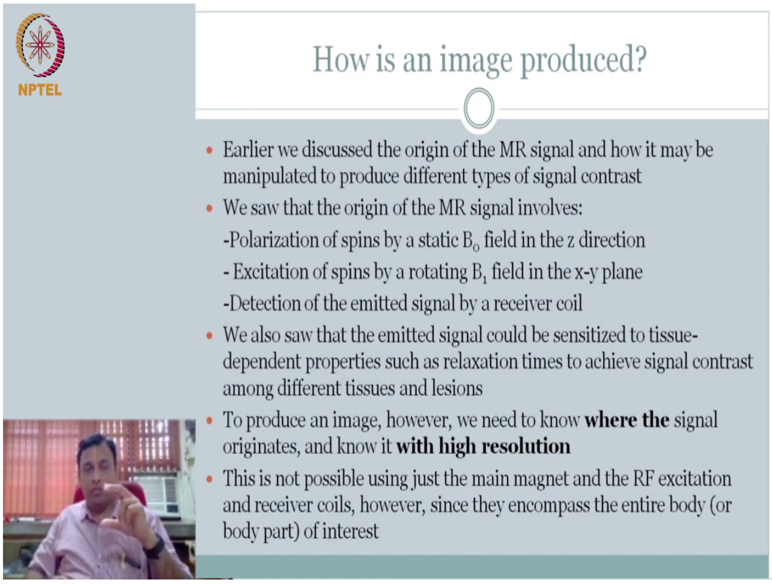


Welcome back to the next session. I hope you had a chance to read the or go through the video lecture on the instrumentation or the components used. So, now, what we will do today is in this video and subsequent 2 videos we will essentially understand move beyond the understanding of just the magnetic you know resonance principle and the spin physics and the instrumentation to how is it that they are going to form an image right we are interested in imaging.

So, we would like to see how we are able to convert this knowledge that we have on MR signal and in fact, not only that not only MR signal. We also saw how it can we manipulated to get different types of contrast right. So, we talked about polarization of the spins in static field and then applying RF excitation or the B 1 field in x y plane and then we can detect the signal using a receive coil.

And not only that we also before they talked about different ways to whatever you are receiving right how can we make sure that that is sensitive to certain attributes of the tissue property right your t 1 t 2 proton density right. So, we know all this, but what we do not know is whatever you are recording right of this property what are we are recording of the signal where is it coming from.

You need to know in imaging, you need to know where the signal is coming from which location precisely at high you know very precisely at a very high resolution only then imaging make sense. Just to say ok I put this patient and this is the signal I am getting from him may not be meaningful right. So, we should be able to tell the distribution of the oak cells of different properties. How do I know what I am measuring is coming from a particular oak cell right particular location that is the key.

So, to produce a image we need to know this spatial location encoding; however, we cannot do that with what we have studied only with the you know magnetic field the static magnetic field and your receive coil or your transmit excitation only these two we would not be able to study.

But we took a volume and we used static field and excitation field to understand what signal we got, but that is not sufficient what is sufficient we need to have some more information right. We need to be able to locate code encode different locations with something unique therefore, we can tell when we get the signal it came from that particular location right.

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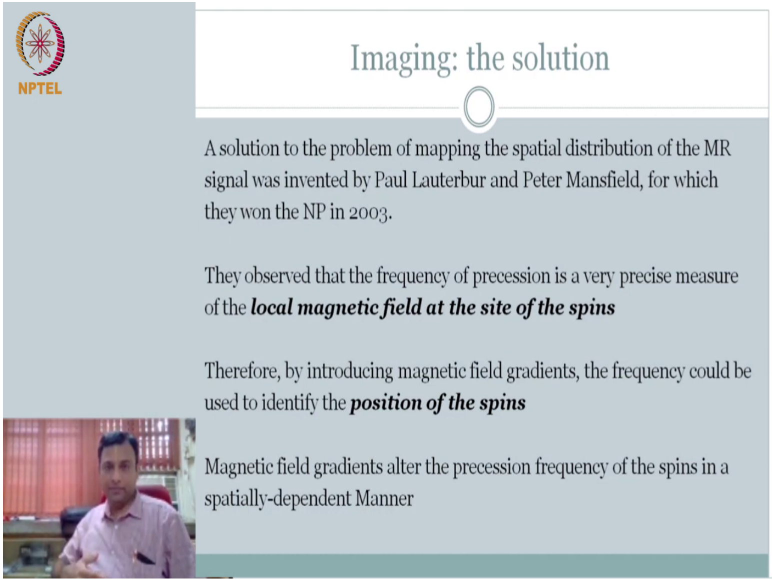


It is not a trivial I mean by no means this is a trivial extension, imagine recall that Nobel prize for the NMR for Bloch equation was given in you know 19 early 50 1952 or something for the work done in 1940s ok. And then Nobel Prize for putting the MRI magnetic resonance image right MRI.

From MR signal were given to Lauterbur and Mansfield only recently the recent in the relative sense is 2003 less than 2 decades ago right. It is always renewed in my mind as recently because I was a graduate student working in imaging and I suddenly you know big buzz about person getting from medical imaging. So, that time it was 2003 so, it was all very renewed in the mind. So, I always tend to think it is recently, but I know years are passing by.

So, but it is still recent enough right, but more importantly what is important what is critical year to observe is from nuclear magnetic resonance right Nobel prize was given in 1952 for the 40s work. These people took you know that concept and put it as an imaging system in the 70s and they got the Nobel Prize in 2003, but essentially the work was done in the 70s. So, cool 2 3 decades above after understanding the physics of nuclear magnetic resonance.

So, we have just spent about maybe 4 lectures or so finishing the nuclear magnetic resonance physics. We are just jumping here so that imaging solution thinking as though it is a very straightforward extension or a very intuitive extension right. So, I think you have to appreciate the complex it is not trivial I am going to make it present it so, intuitively try to pretend that you know this is very common sense way of doing it.

But then you have to appreciate by you know in you have to really be ingenious to think about all this, complex thing have your own understanding and interpretation ok. So, what they basically noticed is the precision Larmor frequency right they notice that is a very precise measure of the local magnetic. We know this that is what nuclear magnetic spin was you apply a magnetic field all the spin starts through align and precess around the magnetic field right this was there.

But what they noticed is it is very sensitive meaning if I change the magnetic field slightly well Larmor frequency also changes very precisely ok. So, that that is a key observation once they unlocked this observation then they said I have a whole volume how do I say that each location is different right or the signal that I am receiving I should be able to say that it came from different location.

They said if this is true then all I need to do is introduce gradients right introduce changes in magnetic field. So, that each location is experiencing a unique magnetic field right slightly different magnetic field. If each location is experiencing slightly different magnetic field; that means, it is going to experience or it is going to have slightly different Larmor frequency.

So, the cool idea was by introducing magnetic field gradients the frequency could be used to identify because, if I have different field strength then the precision frequency is going to change. And so, if I can measure the signal at a particular frequency I know it came from that location right very neat.

So, essentially magnetic field gradients alter the precision frequency of the spins in a spatially dependent manner. So, now we are going to see in a systematic fashion how it was done ok.

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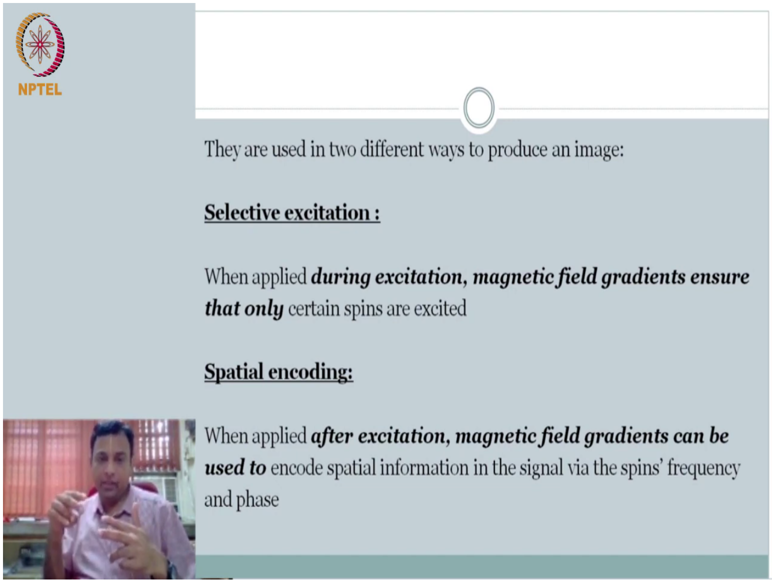


So, that could you could think about it as two broad steps or two different ways of producing an image. So, notice we will restrict our attention to only 2D imaging clearly if you just blindly imagine the first principles that we covered; that means. I can actually excite all 3D and get the signal. If I can get all different frequencies in the same signal I can analyze and say this came from that location that came from that location because the frequency is uniquely identified.

But you know so, we are not interested in volume imaging right now or the complexities with that. For simple introduction we will do the 2D imaging that is I will take a slice. So, I have a image ok that is what we are going to do. So, you can do two things the idea is I am going to reduce the 3D problem into a 2D problem right.

So, how do I get rid, of I am a 3D volume so, how do I get 2D image I have to select a slice right we know the normal axial slice sagittal. So, if I can select a slice then that image is a 2D that we are going a talk. So, I have volume I have gradients that I can apply in all x y you see that is what we saw in instrumentation.

So, if I want only a particular location right to respond what can I do ok I put it in the magnet I have everything aligned in the z direction. Now, I can also actually apply gradients right so, each location as a different magnetic field, but instead what I will do is I will try to apply the magnetic field and then what do I need to do, I would apply my RF excitation what frequency will I apply RF excitation? I have to apply RF excitation at a particular frequency well particular Larmor frequency which I want to choose.

So, I can apply my RF excitation during the gradients such that the RF excitation frequency matches only one location right. So, I can select that so, selective excitation meaning I have during excitation is the D1 field the RF excitation that you are doing. So, I have magnetic field gradients to ensure that different spins are there exited I mean different spins are there different Larmor frequencies are there. When I am applying excitation I will apply excitation frequency.

So, I will know only those location that match to this excitation frequency is going to even respond for the excitation right that is the whole idea apply B 1 at omega naught that is what we covered. So, now, I am going to apply B 1 at a particular frequency wherever that frequency is there in this 3D volume only that location is going to get excited.

What do we mean by get excited; that means, it is going to your signal is going to always in the transverse direction. Excited means only those locations as long as you apply the RF excitation only those locations will start to move towards the transverse plane giving out signal ok.

So; that means, if I go to measure the signal record the signal I know it came from only those locations which had the RF excitation frequency right. So, but once I get it is still going to be volume right I am going to get only a volume, because I can apply only you know if I apply gradient in one direction I can apply RF excitation only within a certain frequency right.

So, that is going to select ensure that I am going to have 3D collapse to 2D so, when it falls on the on the floor I still have everything from that volume right or for that imaging plane. Now, what I need to do is somehow peace out within the imaging plane the two other dimensions ok. So, that we use frequency and phase encoding. So, we will go into this little detail right first we start with the slice selection ok.

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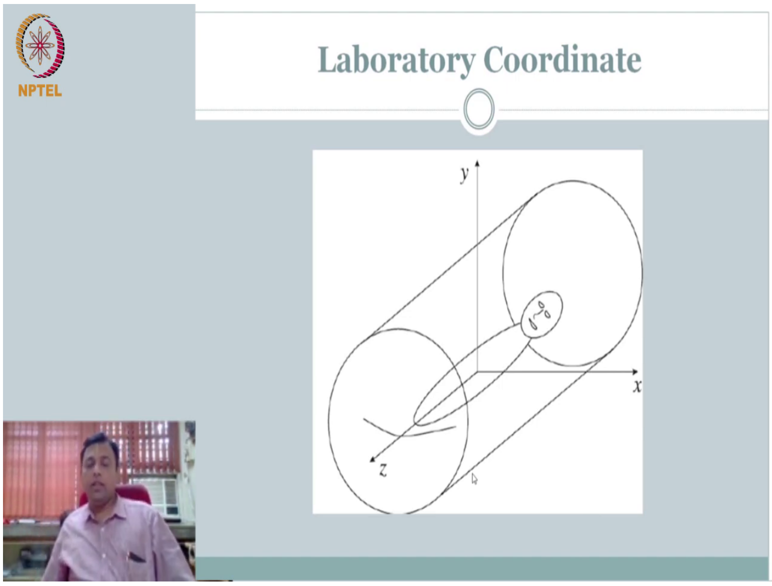

So, before that this is the laboratory coordinates that they are going to use for the rest of the material like I said we are even though I the physics place we covered always z as this way and transverse was floor. I told you when showed the MRI photo that z axis is going to be along the patient lying axis.

Specifically here actually if you notice the text book he puts the feet right head to feet as the positive z and therefore, using right hand you know right hand thumb rule right. So, this is what is like this is my z axis this my x axis, this is my y axis that is how the text book does it ok.

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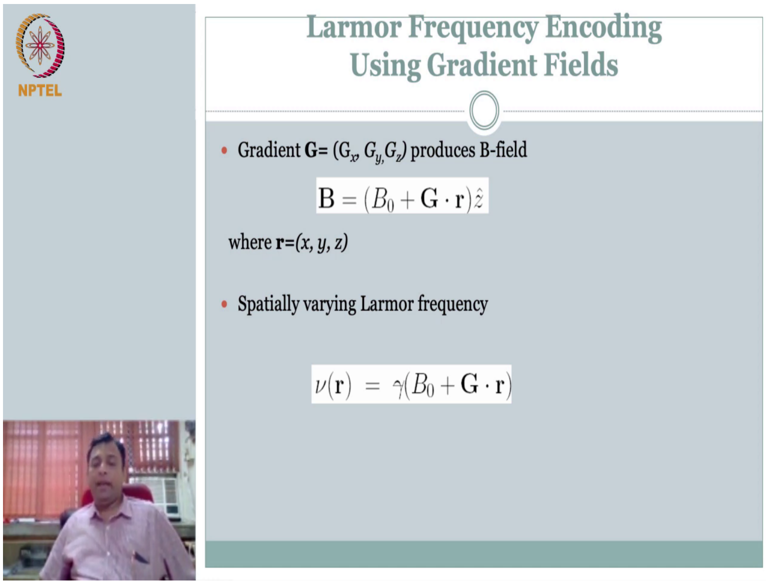


So, now what I will do is first we will start about first type of selection right. So, the idea is very simple I can apply my gradient I will call G x G y G z. So, that my net magnetic field is going to be or the static magnetic field right is going to be B naught plus this r; r is a vector which is encoding a x y z clear. All almost you will see always our direction of magnetic field is predominantly going to be only along the z direction ok.

And so we know from before magnetic field strength is related to Larmor frequency. Since the magnetic field strength is a function of r a Larmor frequency is also a function of r that is it is spatially varying in this manner. So, this is what we are going to exploit ok.

Now, it is 3D r is x y z how are we going to reduce this 3D problem to a imaging problem, first is reduce one variable meaning select your imaging plane after select the imaging plane within the imaging plane how is it distributed right that is what we are going to see.

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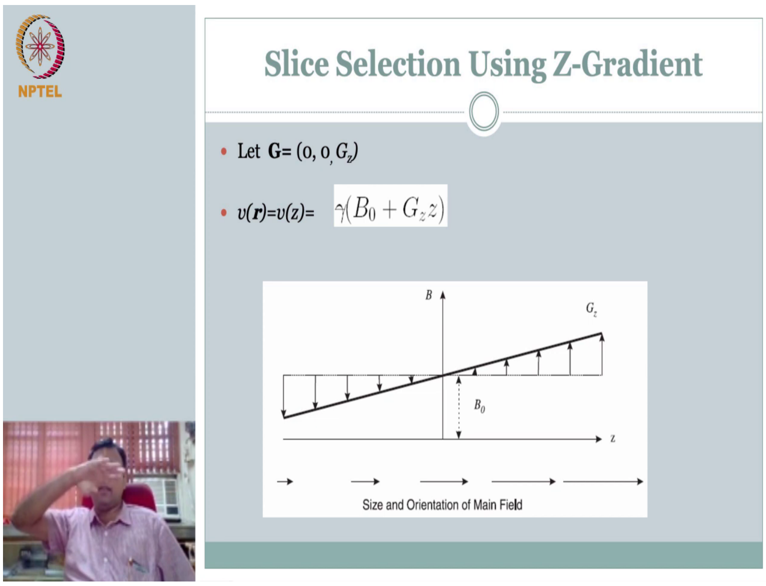


So, first you have selection we talk about slice selection. So, when you do imaging you always select at slice first right when you show an image you say this is a slice of axial slice sagittal slice. So, image you have is a slice right so, it is a slice selection you use what is called as Z gradient what do we mean by use Z gradient that is my gradients I only apply G z.

So, if I apply G z right I have my Larmor frequency will change only in the z direction or vividly if this is head this is tail the foot you have one magnetic field at the head because of the gradient at G z the magnetic field changes from head plane right different planes axial planes.

In the example that we have seen in the jargon that notations that we are using. When we change the Z gradient I am changing the axial slice location right I am seeing the axial size head is experiencing axial plane here is experiencing one magnetic field strength and therefore, one frequency here is different here is different each plane is experiencing different magnetic field strength. Within that plane right in the x and y direction everything you experiencing the same in that plane in plane is same, but out of plane the magnetic field strength is different and therefore, your Larmor frequency is different.

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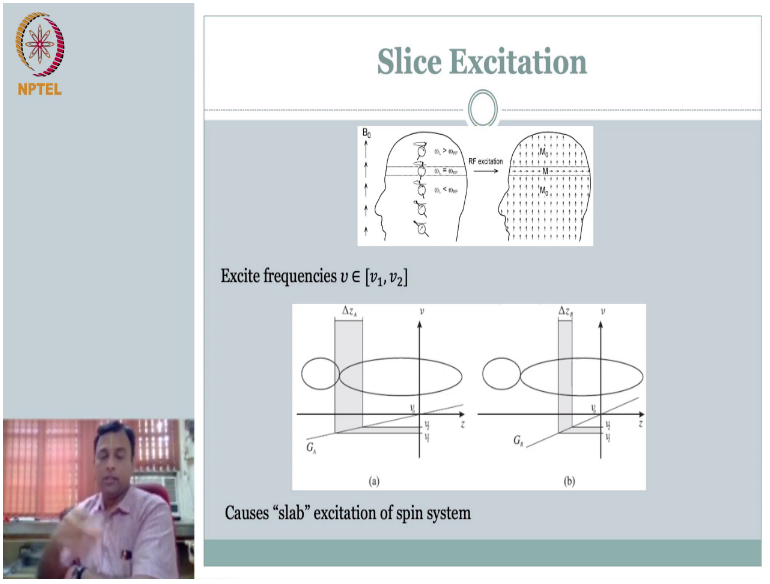


So, now you understand that another. So, now, you understand if I have different frequencies right. Because I have different field strengths when I am applying RF excitation at a particular frequency right that particular frequency wherever it is matching only that slice that location will start to respond right.

RF excitation I am applying a particular frequency right, wherever that particular frequency is along whichever plane corresponds to that particular RF excitation only that plane the Larmor frequency will start to get excited rest of the places it would not be excited right that is the beauty. So, now you know in one stoke when I apply RF excitation at a particular frequency I can select a particular plane right beautiful.

So, let us think through this little bit. So, what are the parameters that I have of course, ideally speaking I have only one perfect frequency only one single frequency I have to excite. But if I going to I excite it with a small range right v 1 comma v 2 or frequency 1 comma frequency 2 there is a small bandwidth it is not a perfect sinusoid at one particular frequency they are going to have a small bandwidth.

Then what happens if there is a small bandwidth; that means, you are talking about small bandwidth in B or spread in magnetic field strength. So, the locations are going to be non infinitely thin meaning it is going to have a thickness right. So, you are going to have a slice thickness in the spatial domain, but in the RF excitation we will talk in terms of frequency bandwidth right.

So, you can see I mean, here I have two examples or two different field strength. So, I said field strength is applied only in z direction. So, here I have a field strength magnitude is G a here the field of the gradient is steep or shallow right, you can have different gradients. But it is all only gradient in z direction you see the effect already.

So, if I have the same RF excitation frequency that I apply depending on the gradient I actually have two effects that I see one is the thickness is changing the other is even the location is changing. In fact, to be honest you look at this v 1 and v 2 is same that is I am applying the same RF excitation, but then depending on your gradient you can have a thicker slice or a thin slice, not only that here it is the neck region here it has already come to the chest region.

So, essentially by controlling the gradient I am right the G z amplitude of the gradient and the magnitude of the gradient and your frequency of excitation. You can select whichever slice you want from whichever location you want and the thickness can be controlled right. So, let us put it in terms of equations that we know.

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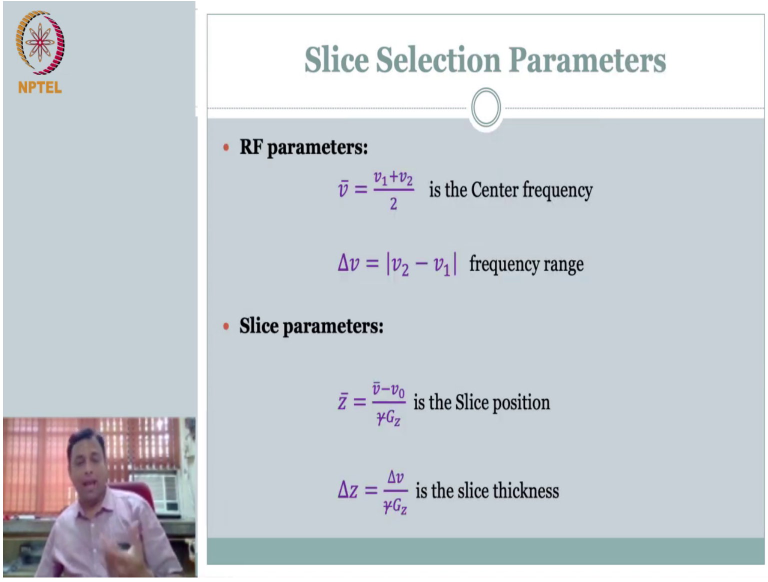


So, the parameters that we are interested now are RF parameters which are as a center frequency and a bandwidth and then the slice parameters which has the slice location and slice thickness. What you need to notice is we are interested in imaging business. So, they are going to say the image is from you know at this particular location of the brain. So, we are interested in slice position and thickness of the slice.

So, the engineers or the control the console is going to give parameters that is going to choose the frequency such that the physician or you know the radiologist can do a study at a particular location. This usually will be a user input or the radiologist input. So, frequencies would be changed so, that this position is chosen.

Because everything else is in your control G is instrumentation parameter v 1 v 2 are all your parameter gamma is you know material property, but here biomedical we said it is all about hydrogen. So, we can always you know calibrate everything else correct.

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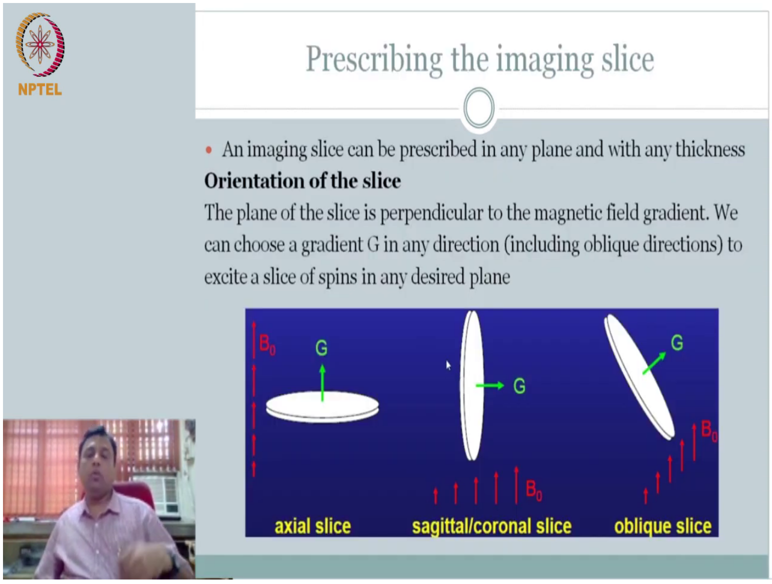


So, now just because I showed you G as the slice which is the axial slice. In fact, the beauty about MRI is this if I applied only instead of G z if I applied only G x or G y I could have selected you know sagittal or coronal. Not only that if I apply you know all of them together in different proportions I could even get oblique slice right.

So, this is the starting point of the beauty of this modality you have so, much freedom to do what you want. For simplicity we will keep it you know in the x y z that we have the orthogonal. In fact, even that we will first talk about a z as the axis slice and we will continue, but you see the powerfulness of what we have covered so far. Understand the concept you could do whatever you want ok.

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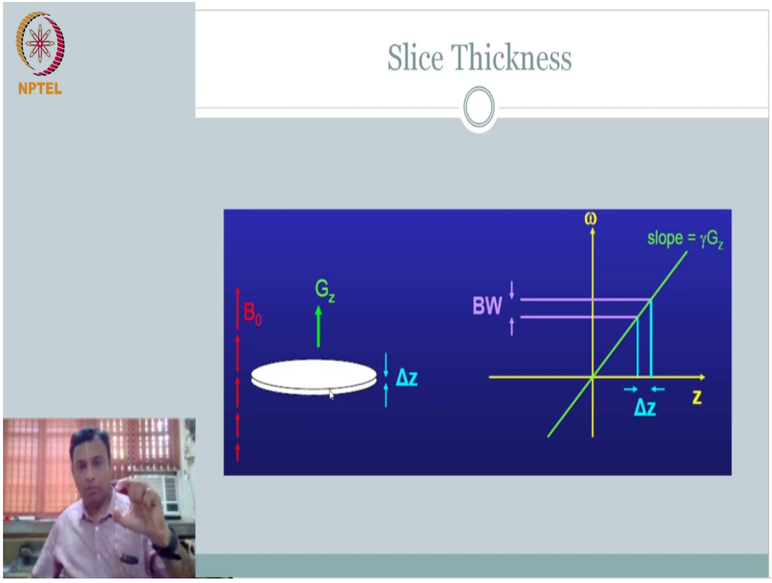


So, just to put it in summarize and move forward. So, we have the spatial domain where we are interested in selecting a slice location of the slice thickness of the slice, this can be controlled by the gradient and the frequency. The frequency of the RF excitation the bandwidth of that along with the G z controls the location and the thickness of the slice ok.

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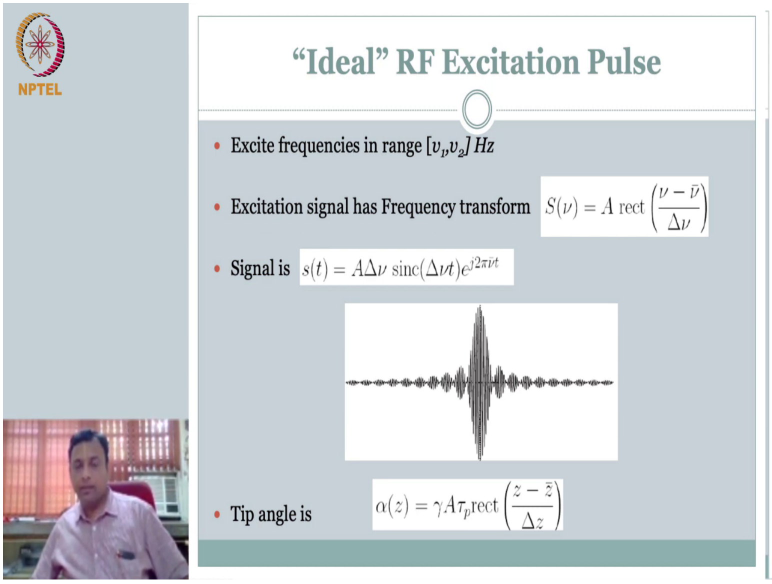


So, now ok we have seen that we have to apply RF excitation within a chosen bandwidth what is a ideal RF excitation. That means, it is a hard limiting that is I have you know the frequency response right is a rect, meaning I have all the frequencies only between v 1 and v 2 just after I cross v 1 or v 2 on either side I do not have any signal right that is your ideal rect signal.

So, excite frequencies only if this range v one and v two if you do that; that means, your fourier signal is rectangular in frequency domain right. So, rect in frequency domain, it has only frequencies from v 1 and v 2 anywhere else it is 0 this is your frequency signal. So, if this is a frequency response your time domain that you are going to apply is going to be rect is going to be sync right.

So, you signal s of t will be sync function which is existing for long duration right. So, now, another parameter of interest for your RF excitation is how long I apply this RF excitation that will dictate my tip angle which you know which is related to the gamma and your apply excitation pulse characteristic A tau t rect of this one ok.

So, let us jump in to see what. So, if we this is the ideal signal that we are applying what is the signal we are applying this to you RF excitation that is your B 1 magnetic field B 1 has to rotate or no do and that is given by this s of t this is the input to the B. So, the B has to be applied excitation has to be excite.

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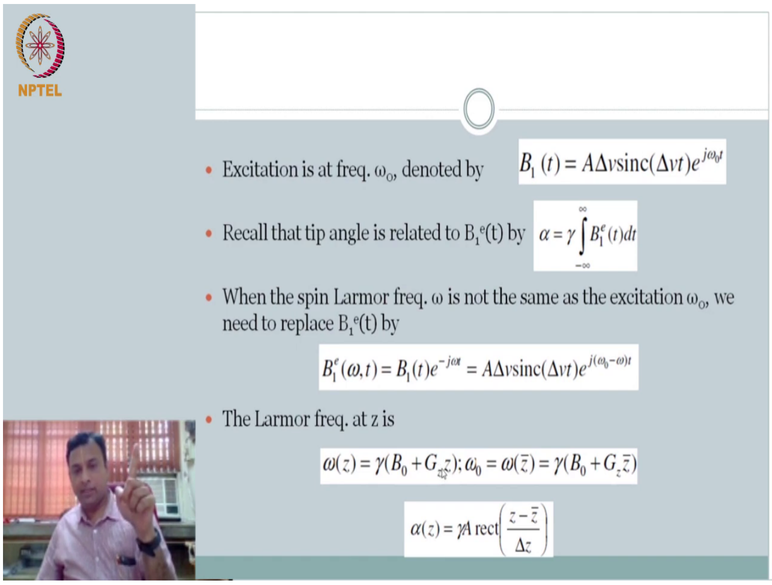


So, excitation at a particular frequency we know how to denote right is a sync function with a particular frequency. Of course, we also talked about relating that tip angle to this envelope of

B before right. So, now what happens if you have a different slightly different frequency than omega naught right.

When the spin Larmor frequency omega is not exactly same as omega then we need to replace this B e with e power omega to essentially you have a signal which has omega naught minus omega t right. So, this is my envelope signal which is envelope this in a sync format this is what I am applying in the excitation.

So, what is going to be my you know Larmor frequency at a particular location z I know the relationship between field strength and Larmor frequency they are related through your ferromagnetic ratio right. So, omega frequency at a particular location z is gamma times whatever is the magnetic field strength at that location B naught plus because we are applying only G z it is G z right.

What we are interested is we are this is ideal at particular z, but we know we are talking about thickness. So, this is center of the thickness z dashed so, omega naught is at the center of the thickness will be gamma B naught plus G z at z center right. And therefore, your alpha z will b this term what is this saying where alpha z is also rectangular that is what you want to see at that look.

What is alpha z rectangular means? That means only the spins within the slice thickness are responding to this alpha right that is what you are exciting; exciting means if you apply and keep it on you are trying to push it to the floor. You are saying alpha is also changing only for z minus delta z by 2 to z plus delta z by 2 or within this r limited bandwidth.

So, essentially this is saying if I apply a ideal excitation which has only signal in a particular bandwidth then excitation alpha is also going to be only from there; that means, to stretch your imagination; that means, my signal that I am going to record because remember alpha when I push it to the floor you get the maximum signal. So, whatever signal I am going to get is also going to be from this ideal slice thickness, but nothing is ideal right.

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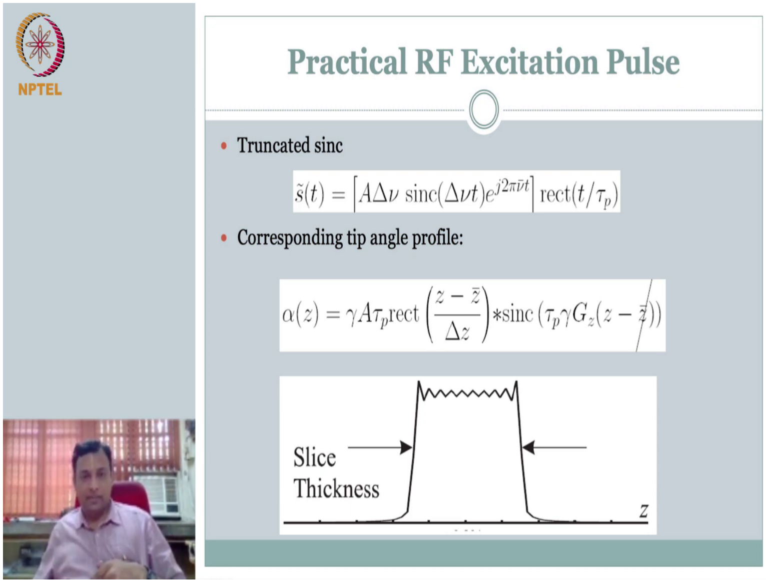


Practically what will happen they are going to have some you cannot apply everything you are going to have some a truncated sync is what you can apply here you have some finite time right. So, when you truncate it what is going to happen your frequency is not going to be hard limiting it is going to slope out right. So, your slice thickness will not be a rect your slice signals will be there will be a slope that is you are going to have some blurring.

So, practically speaking even though we are selecting a slice thickness we are saying it is from z dashed minus delta z by 2 to z dashed plus delta z by 2 that is your slice thickness. Reality you are going to get some signal also from the thickness as it is you know outside this thickness because it is moving.

How well you contain this is a trade off that you usually do right very same concept of your windowing in signal processing same thing applied here in the spatial domain ok. So, let us leave it at this we say we understand what this is what is more important for us to understand is, ok. By doing this right I am going to measure do I good do I get signal I said RF excitation to all excite within this thickness, but do you think you will get signal out of this why am I asking that question.

Because remember how we signal comes when everything is coherent right, but what I have now is within this bandwidth I have different frequencies right.

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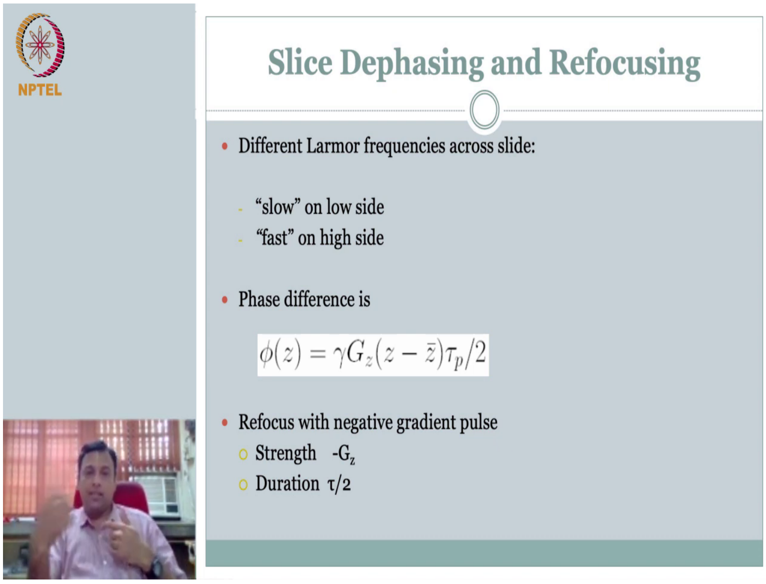


So, you can before do any further if you think about it within this thickness I have z bar right center of the slice minus delta z by 2 plus delta z by 2 right the either end cell. I have slightly less magnetic field in one direction in on one end I have slightly more magnetic field strength on the other end right because there is a gradient.

So, what is going to happen; that means, this side the precision is going to be at certain level one end it will be lower precision the other end it will be faster. So, here is going to spin slow slightly compared to the center and that one is going to precess slightly faster compared to the center and therefore, there is going to also be some phase shift right.

So, what is going to happen the net effect is from this volume slice thickness volume you would not have coherent addition each one will cancel each other. So, you would not get coherent signal. So, if I have to get coherent signal what do I need to do somehow, I have to make everything you know spin come in phase and then spin at the same time. If I do that then I will get coherent signal although.

So, slice dephasing means within the slice there are different phases and therefore, you would not get signal you have to do refocusing to get the signal. You just put so, different Larmor frequencies across the slice gives rise to slow speed and fast on the other side and therefore, there is a phase difference also from minus to plus of your thickness right.

So, there is a need solution what do you want to do if I can make everything coherent; that means, the slow guy have to become fast guy have to become slow, if we do that then they will all meet. We talked about similar things when we try to do the spin echo just go back and remember same logic.

Here what we will do is we will apply gradient the same G z, but a negative right initially we did positive G z what happens if I do negative G z the field strength that was high that location will become low the location that had higher lower field strength magnetic field strength will become high; that means, the precision it was it was doing fast.

Now, I have flipped to the gradient and therefore, it is trying to become slow. Wherever it was slow now because of the flip it is going to try to come fast. So, you can notice that the moment I switch the gradient the one extreme and the other extreme are all trying to cross path and go to the other direction. The slow side should come to the other fast side should go to the other direction.

So, when they when they when they cross this path so, after you apply negative polarity immediately thereafter this is signal will start to become increasing because it is getting nowhere, sometime it is going to give maximum and then it is going to die down right.

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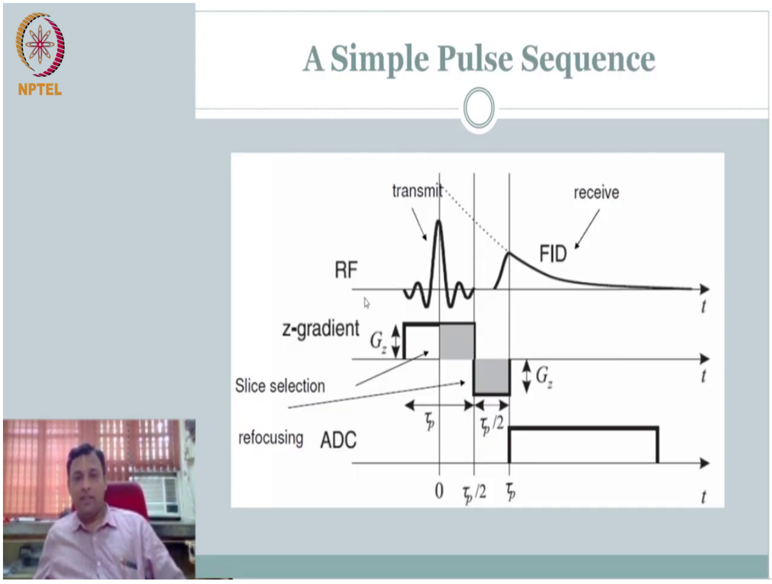


So, put it in pulse sequence diagram that we have seen I applied transmit while I am applying the excitation I am applying my z-gradient. So, I know this is called my slice selection only that slice is going to respond to this excitation; that means, I am expected to get signal only from a chosen slice, but you do not have any signal because of lack of coherence dephasing.

So, immediately thereafter when I switch the excitation pulse, after I switch off the excitation pulse just immediately thereafter, I do gradient switching the positive G z became negative G z. And I apply it half the duration right because it is positive phase on the other direction there the phase difference by 2 is what you have. So, you want to make that come together so, tau p by 2.

So, the moment I apply this the signal starts to go up. So, now the signal I mean naturally it will start to decay again the free induction decay because excitation is off right. So, it will start to decay and I am going to record my signal as a free induction decay so, this is your analog to digital converter. Essentially we are saying you are recording the signal and digitizing it this is your recorded signal ok.

So, we will proceed with the, we have volume now we know how to record a volume and how to interpret in using a how to explain this using a pulse sequence diagram. So, now what we need to do is you can already start to intuitively imagine I have a volume I know the signal is coming now from the obtained signal how do I say it came from a particular x comma y right z is gone. So, within x y plane whatever I am measuring how do I say it came from a particular x comma y that we need to see ok, that we will see in the next lecture.