Introduction to Biomedical Imaging Systems
Dr. Arun K. Thittai
Department of Applied Mechanics
Indian Institute of Technology, Madras

Lecture - 45
MRI_Phys_S40-S44

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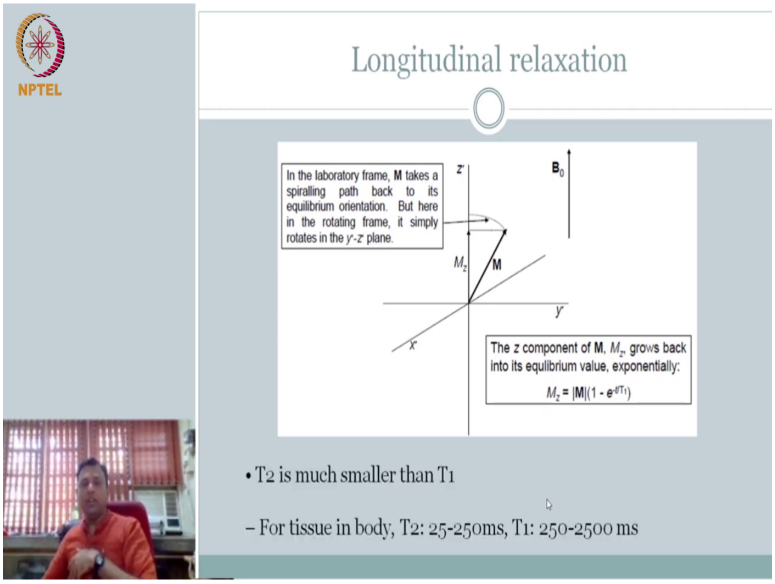

And the reason for that is we are just going to complete one important concept that is related to the T 1 and T 2 star that we were talking about and to do with recording the signal right your decay signal in relation to application of excitation pulse. What we covered so far is if I apply pi by 2 pulse I get the maximum signal and all our illustrations that we have shown we have pushed it to the floor allowed it to dephase record the signal and the this is a T 2 star T 2 you know there are two relaxation times involved.

So, the decay in the free induction decay that you saw right it started with a maximum value and then with the time it decays initially it decays faster due to the T 2 star effect and then it continues to dephase due to T 2 effect and then eventually the signal goes to 0 on the other hand the M z component increases. So, your T 1 due to T which we called as T 1 relaxation time ok. So, now, the question is I can play this game every time I can follow the excitation push it down record the signal no issues.

But, now the question is there are one more capability that we can do that will allow us to notice this T 2 or T 1 both of these are also characteristic of the material right or the or the sample volume. So, if you are talking about hydrogen if the neighbors are slightly different at that location then you are going to have a different T 2 right and so also depending on the loss you are going to have different T 1.

So, different locations depending the volume that we started with which have the signal have proton density. So, the signal that you are getting one is the characteristic of the material with respect to having the proton density that is dictating your value of M. Now, in addition to that we have talked about the decay called the relaxation time itself is a characteristic of the sample material ok. So, that is T 2 and then there is T 1 that is also samples ability to lose right some material lose fast and then they gain come back to the equilibrium faster it is has to do with the energy loss. So, this is also a material problem.

So, now we have different material properties which is all somewhere there, but how do we how do we measure this at each location that is going to be the challenge that we are going to talk about. So, in order to do that we already understand that we need to have flexibility in pushing this down recording how fast we push, how many times we push, all these are parameters that is under your control, you have the ability to on the excitation pulse, off the excitation pulse, how long do you want to on, how long how frequently you want to on is all in your control.

So, therefore, there is one another important concept or one important tool right to play this game you have which is I have a echo sorry I have a signal which is transverse. I know the signal is coming only from the transverse component now we talked about dephasing so, the signal is going down.

So, what happen say if I want them to rephase again right. How do I make it rephase again? One way to do it is well, what is the meaning of this dephasing some is going for right remember why is it dephasing, because some nucleus, some vectors are some nucleus are moving faster, some are moving slower slightly up and down the larmor frequency.

So, what happens is they start to move away from each other. So, now, if I give another command right and say oh whoever is moving fast you start to slow, whoever is moving slow you start to move fast if I give that command right if they know how to do that then what will happen. The slow ones will start to move fast, the fast ones will start to move slow and therefore, that after you tell that command within few time they will start to become coherent again right, again after you finish that command they will have their own ability to dephase again.

But, the point is by having additional command I can make them come to coherence again. What does that coherence has what does that command had to do, that command has to do with making the faster ones to slow down and the slower ones to fasten up right then I can do it. So, how do I implement that command?

Now, you recall we talked about of course, you have to apply excitation pulse I mean you have to have additional excitation pulse that is a given. So, now, the question is how will you apply the excitation pulse or how long will you; you are already on the floor right. What are you going to do if, I apply another 90 degree pulse it will go down more transverse component. So, it does not make sense right. So, what will I do? So, this is where the other pulse that we talked about right pi pulse first is pi by 2 pulse, then we talked about pi pulse.

Now, you say you start here if you apply pi pulse what will happen, there should be a 180 degree shift, what does that 180 degree shift, which is all still going to rotate in this direction, but what is 180 degree going to do, it is going to essentially change the polarity. So, who was going fast as to come down, who was going slow as to fasten up it will achieve the effect right.

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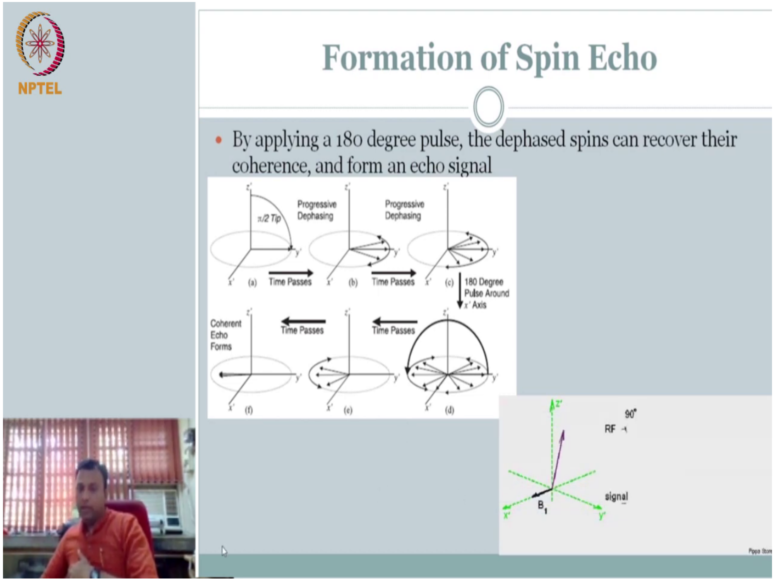

So, we are going to talk about formation of spin echo formation of spin you know that is what we have covered so far. The new term here is echo what is an echo, echo is a reflection right. It is a you have a signal echo means it is a repeat of the signal a poorer cousin of the signal that is what is a echo.

So; that means, spin echo means I have a signal from spin, spin echo means I have a signal from spin echoed again, meaning I have the signal it is trying to signal is going to go down I am trying to make it come back and record it again. So, that is your echo of the signal. So, by applying 180 degree pulse the dephased spins can recover their coherence and form an echo signal. So, here is the completion of the time sequence that we had.

So, initially we had time. So, you did the pi by 2 all of this is in the rotating frame of reference. So, you have z dashed; z dashed is pushed down because of pi pulse the after the first hour of excitation pi by 2 excitation it starts to dephase, you allow time it is starts to dephase completely that is sometime after that you apply another pulse 180 degree pulse now. If you do this 180 degree pulse it will essentially move it to the other direction it is in this direction you are applying 180 degree means it is going to go to the other direction.

So, when it goes to the other direction what happens the slower one tries to become fast, faster one becomes slow. So, it is trying to catch up. So, it is trying to come together and therefore, you are going to have again some, notice that the coherence here is not as good as the coherence here right. Here you see it is a single arrow which kind of says that everything is coherent whereas here you see it is almost coherent that it is not single line it is all trying to achieve coherence.

So, signal is increasing, but it is not as great as this one, also notice you started with this circle right. This is your amplitude or magnitude this radius, the radius is also reduced so; that means, why because it is relaxing there is a T 2 process right. So, it is a reaction signal is relaxing. So, there is a loss in signal that is why this arrow is reducing, eventually this arrow will go to 0 in the x y right it will only be z component.

So, what you have done is by doing this you have tried to recover the signal as much as possible it is not complete, but you have gained the signal. So, it is going to be a copy of your original signal, but going to be slightly lower than that. So, if you want to see the animation right that will give you.

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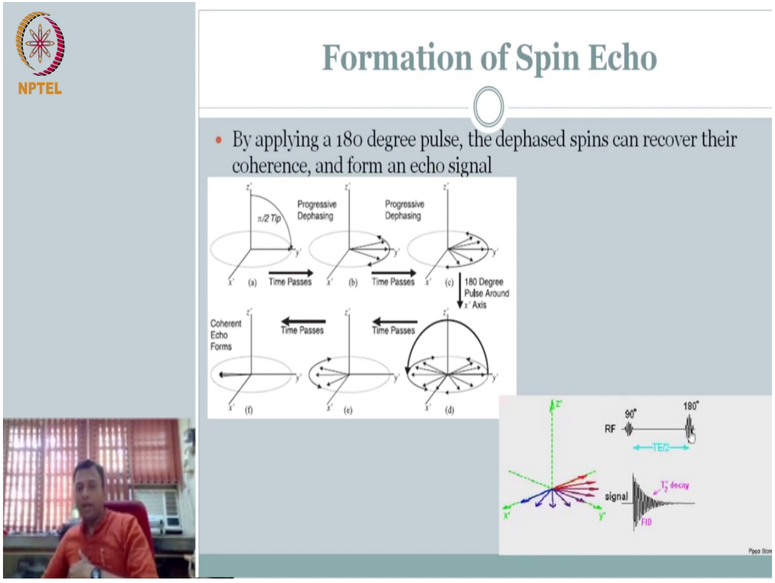

So, initially excitation you have the signal red and blue signifies you know fast and slow for example, it is going some or it is dephasing some are fast some are slow. Now, after you apply 180 degree pulse the slow becomes fast, fast becomes slow so; that means, they are all trying to regroup it is not asked yet.

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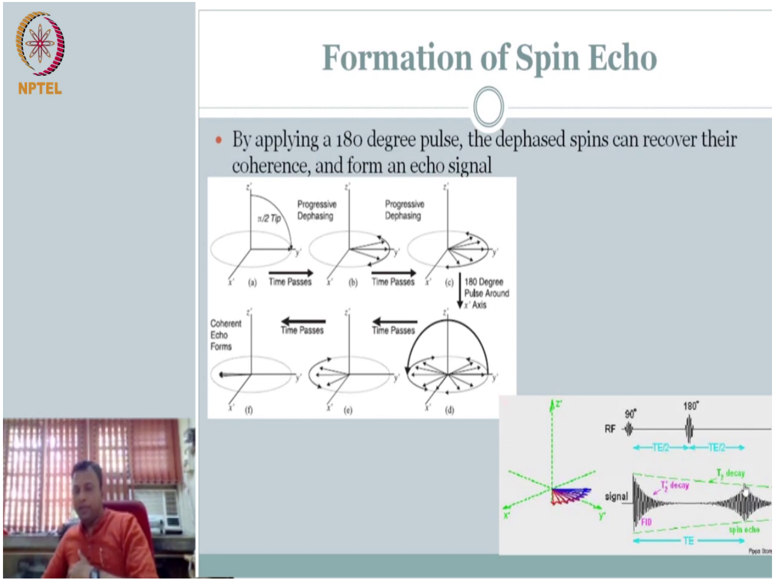

So, now, its signal starts to build again the signal starts to build again after your excitation 180 degree excitation right, 90 degree signal starts to decay decay decay decay decay decay decay I apply 180 degree after some time of application it starts to form back. So, my signal starts to come in signal builds in signal builds in. So, it goes up again the nature has it that it will start to dephase again because you switched off the excitation pulse right.

So, the 180 degree pulse excitation pulse, 180 degree excitation pulse makes it come together and then when the other side it goes down it starts to dephase again. So, again this will start to decay. So, this is the signal, this is the signal right and what you are going to get is an echo of the signal. So, 180 degree you apply you get a echo of the signal. Let me stop here just so yeah so, you get an echo of the signal.

So, therefore, you have timings involved. So, this is time to echo right. So, T 2 we already talked about relaxation times which are all material property whereas now you notice this time to echo is nothing you have control you know when you want to apply the excitation pulse right. So, you are applying time to echo.

So, this timing is also under your control. So, the whole beauty of MRI is you have multiple parameters that is inherent to the material property. You can manipulate what you want to get of the material by changing that and the sequence in which you are applying the RF excitation pulse.

So, now in this case I have applied echo signal I will get a echo signal I have applied a pi pulse following pi by 2 pulse after some T E by 2 type. So, essentially you notice there is inherent contrast due to oh sorry inherent signal due to material property based on T 2 relaxation time, T 1 relaxation time and the proton density, how much of protons are there in that wall move right, that is a so that is a material property.

So, that signal I can manipulate which aspect I want to see of that sample value of that tissue, do I want to see the T 2 characteristics sure, do I want to see the T 1 characteristic of the tissue parameter or do I want am I just happy with how many protons are there in that given volume right, any of these characteristics of the tissue I can get manipulate the signal using the sequence of pulse that I am using. So, this is what is called as a pulse sequence.

The pulse sequence can be manipulated to get whatever aspects characteristics of the material property you want namely here at least in this limited discussion we have three characteristics; proton density, T 1, T 2 of the material, we can exploit, understand characterize, measure using your sequence of application of the excitation pulse and of course, the timing involved when you are recording after how long you are applying all these are parameters of acquisition.

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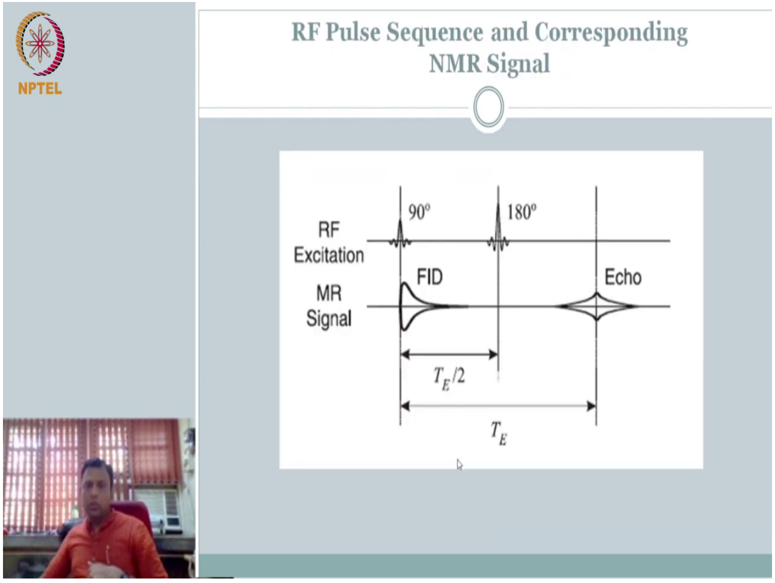

So, just to complete so, we need some way to you know put all these together which is called as a timing diagram or a pulse sequence diagram ok. So, we will expand on this as we build the material, first is you have RF excitation, I have my MR signal, what I am measuring is going to be the echo signal. So, I have to design that T E and T E by 2. So, I need to build this. So, this is called as a timing diagram and a pulse sequence diagram because I know the sequence here 90 degree and then I am giving 180 degree after T E by 2 to get a signal that is a echo signal ok.

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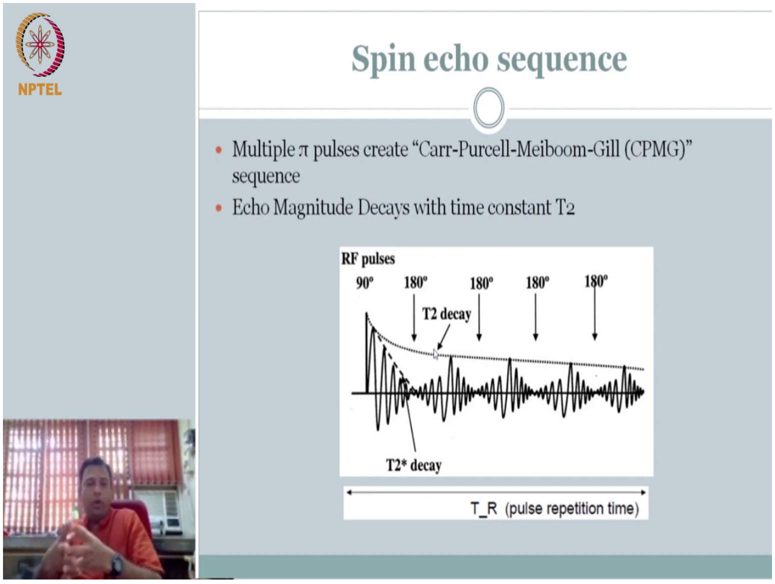

So; that means, I can manipulate there are several sequence people have played with. So, one is a multiple pi can be created and essentially what you are going to get is 90 degree and then you are applying multiple pi's; pi by 2 first pi pi pi pi, but notice each time your signal is not going to come back to the original level, each time the signal is going to be poorer based on your T 2 decay. Remember it is all decaying you are flipping it left right 180 degrees, but then this decaying and the T z is trying to increase with its time constant T 1 right.

So, this is your time to repeat so, the pulse repetition time. So, I can that axis. So, I can do 1 pi by 2 and flip it left right multiple times after I know that signal is decaying due to T 2. So, after two or three times the T 2 value no matter I flip it how many times apply 180 degree any time the signal is going to be very weak right it is going to be very weak because the transverse component is lost your T 1 your M z is increased.

So, after sometime it is not worthwhile flipping it left right because it is inherently poor signal. So, at that time what I will do is, I will again allow it to go back completely and then put the 90 degree pulse again. So, time to hit the next 90 degree pulse will be called as pulse repetition time.

So, you notice this is just to illustrate that you can manipulate the pulse repetition time, you can manipulate whether you want the echo signal, how many times you want the echo signal all this can be manipulated. Essentially, you manipulate this with an idea to exploit that whether you want to get the T 2 characteristic of the signal, p 1 characteristic of the material or just the product density is good enough right. So, all these can be manipulated using the pulse sequence diagram.

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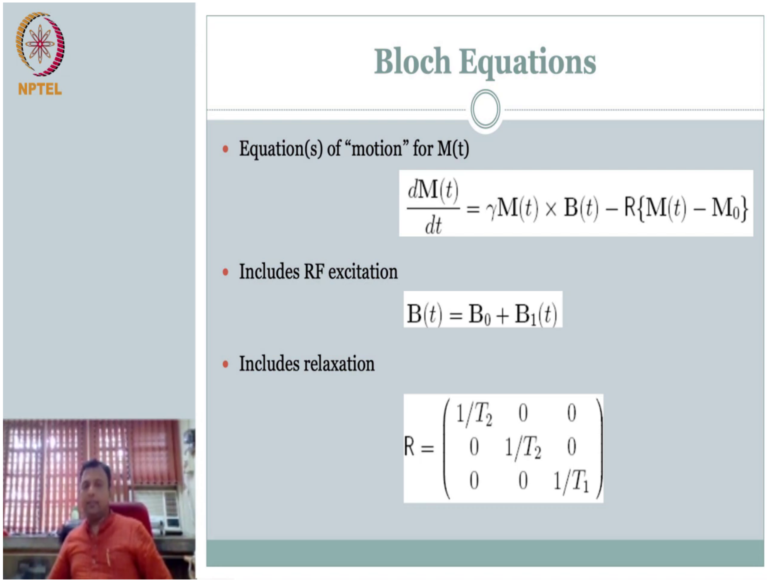

So, just to complete we already had our Bloch equation for motion when you add static we added to the static field the excitation field also the upgraded right. Now, the motion is due to not just the static field it is also due to your rotating field.So, we have to upgrade this “motion” equation to incorporate the effect, we know what the motion is we saw it directly in the animation, but mathematically this is how you complete this is what is called as Bloch equations we started with it is going to have the magnetic field that we had B naught.

Now, this B of t also includes B 1 of t right. So, M of t cross B of t add this of course, there is a relaxation the magnitude of the magnetization vector changes due to the relaxation, the relaxation property is captured using your T 2 and T 1. So, this is your relaxation matrix. So, this is a complete set of Bloch equation which describes the motion of your magnetization vector in the presence of static field and the applied RF excitation field ok.There are couple of examples in the textbook where he expands the vectors into components and you know shows for pi by 2 what is the M x y. So, please have a look at that.

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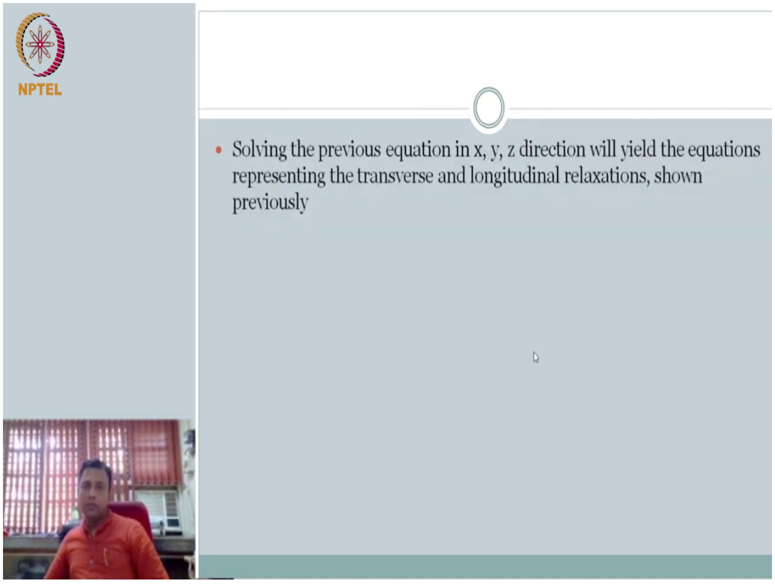

So, solving the previous equations in all the three different directions gives you the equation that we saw already ok. So, just have a look at the textbook on this as well. I hope with this we actually complete the understanding of what is the signal origin, what is that we are recording and how is the recording of the signal changes, the changes in the signal capture or due to the physical properties that we are going to go after T 2, T 1 and proton density, how is that.

So, how do we manipulate all this to see T 1 or a T 2 or a proton density of that volume right characteristic of that volume that how we are going to do will be the topic of interest to us which will be the next to module that will be on contrast in MRI. So, once we understand the contrast in MRI, then we move, our physics is complete then we will move on to how do we accomplish this using instrumentation and signal reconstruction.