Introduction to Biomedical Imaging Systems
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Lecture - 52
MRI_RECON_S70_S82

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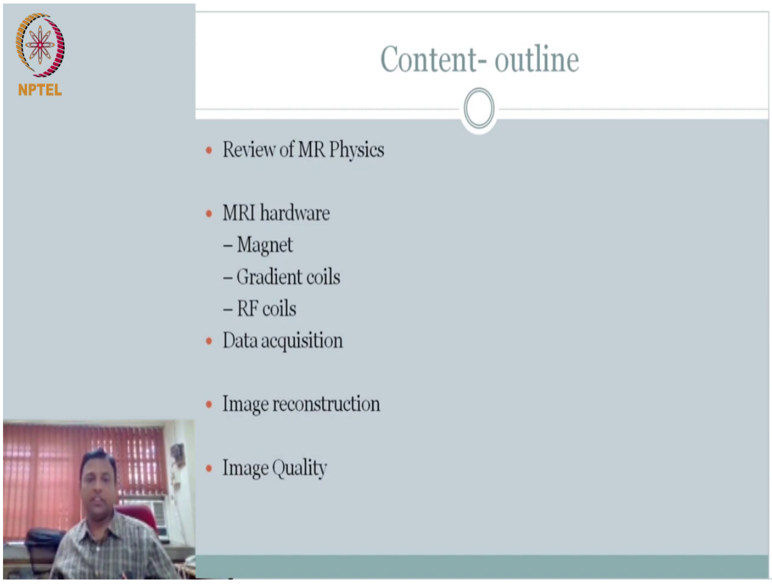

Ok. So, I guess you had a chance to view and appreciate the beauty of MRI recording right the data that we got and why is it that the data that you are recording unlike other modalities. Here what you are recording is actually the Fourier transform even though signal is represented as s of t.

The data that you are recording actually turns out to be the samples of your Fourier spectra. So, you know it is very intriguing. So, now, what we will do is as you will see here this was supposed to be the course content and we have covered until data acquisition. We are still left with image reconstruction and image quality.

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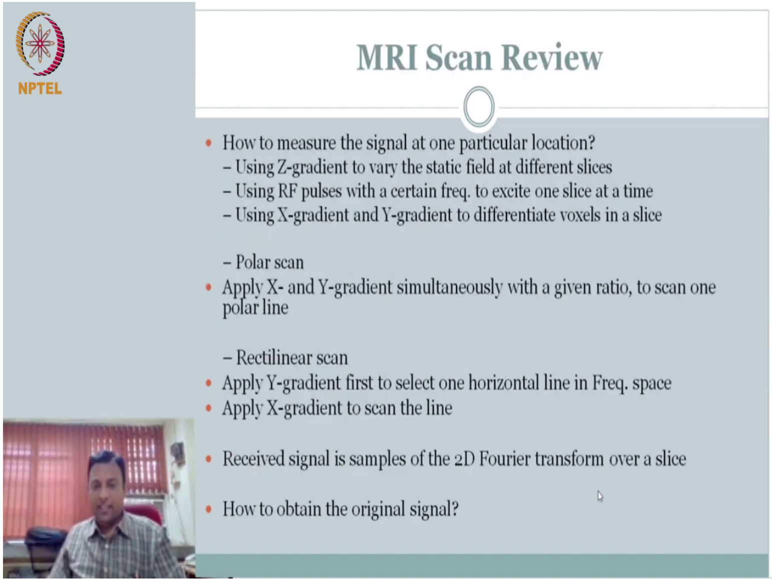

We covered what we will be covering today you know it is going to be very straightforward 10-15 minutes we will finish image recon because there is nothing new ok. So, how do you obtain original signal take, inverse Fourier transform.

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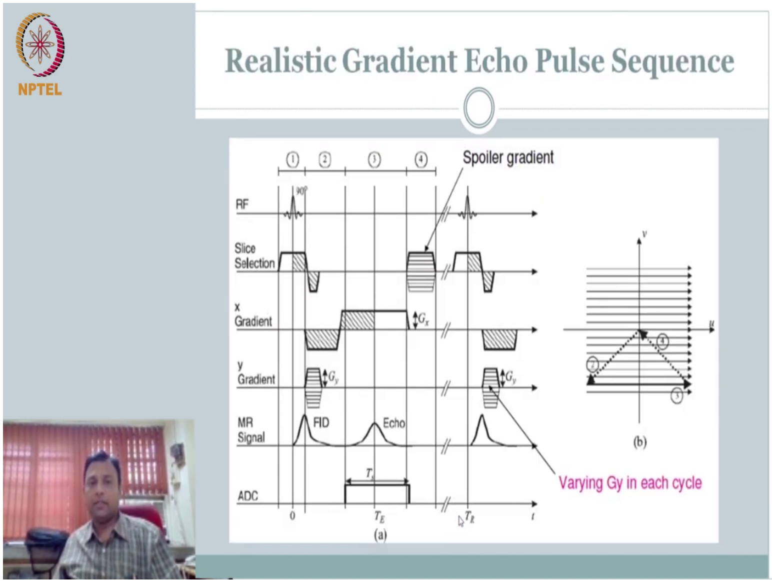

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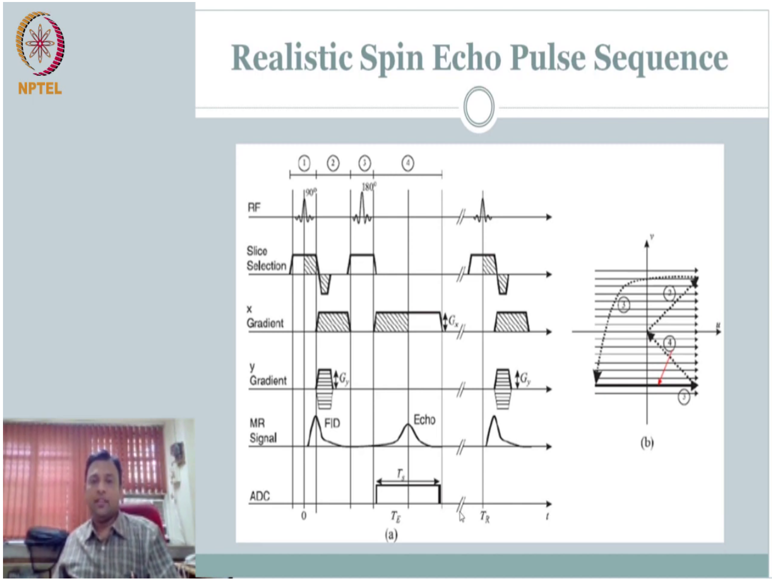

So, I will just spend some time so, always revision of how we do data acquisition to get rectilinear polar.

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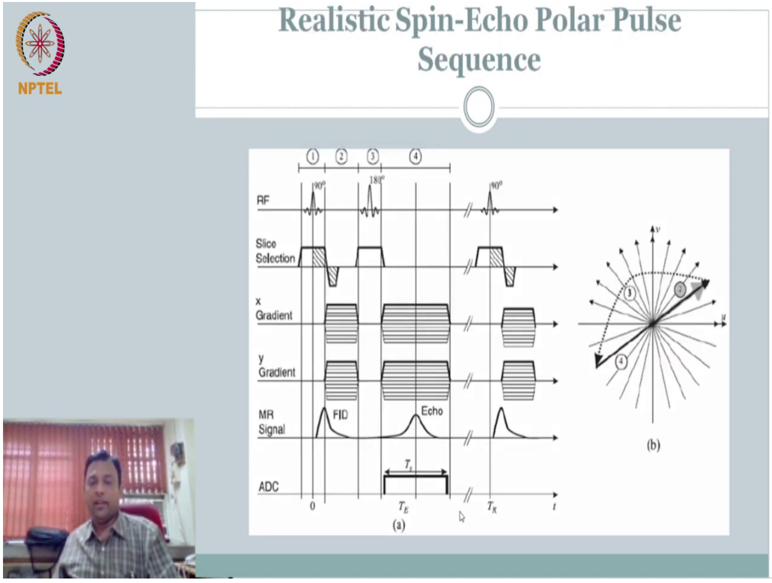

I will not spend time because that is not needed now because of the video lecture.

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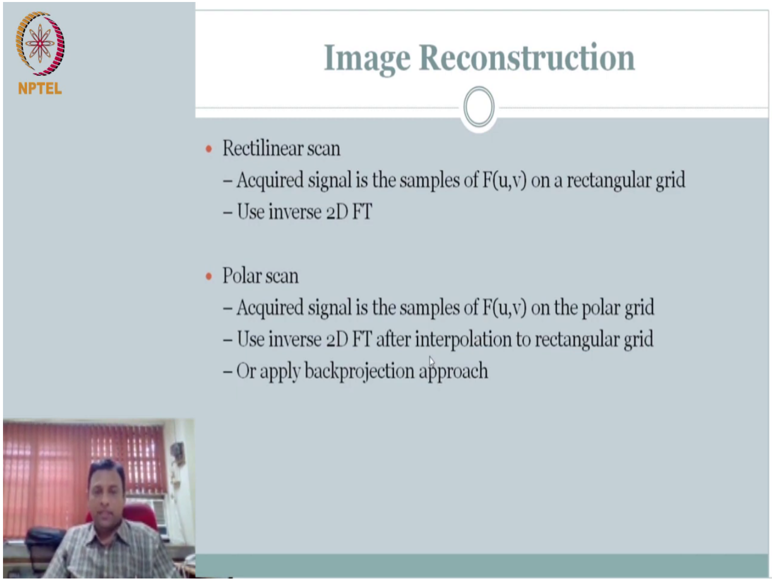

I you can review the previous video. So, where we will go is we will jump into image reconstruction. So, we have two kinds of data one is rectilinear scan the other is polar scan. So, what we have seen is acquired signal actually is we have samples right, we have samples of F of u comma v on a rectangular grid if it is rectilinear scan.

All you have to do is just take inverse Fourier transform 2D F of 2D inverse Fourier transform you will get your image. Likewise in polar scan acquired data already you have F of u comma v, but in polar grid. So, you can either do that you can convert the 2D to a rectangular grid and do it or apply it back projection approach ok.

So all of these reconstruction from Fourier to image we also did for CT. So, several of those algorithms can quickly guide you as to how you can do the inversion ok. So, we tried convolution remember. So, same things can be applied here nothing secret about it ok.

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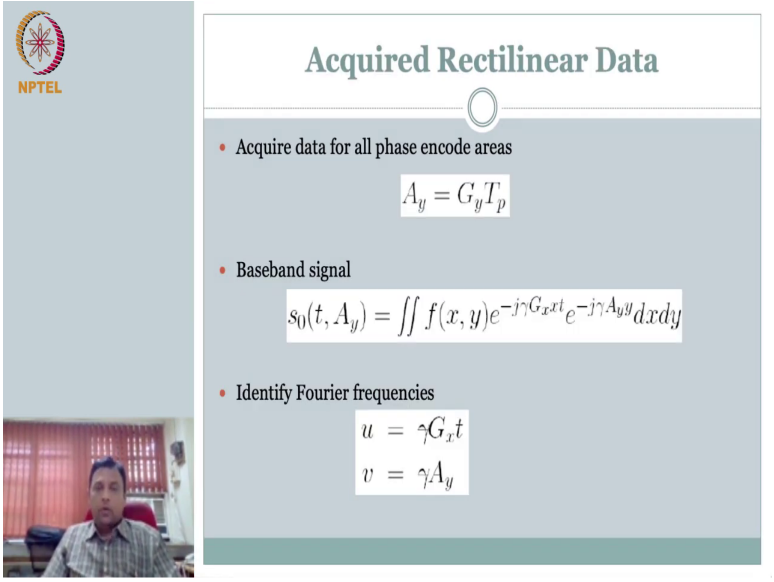

Only thing that I will do is just refresh within our equations what we have and how we start to look at the data or organize the data in a standard format. So, you acquire the data right in the rectilinear scan, you are having phase encoding; phase encoding comes with gradient y, you have the area A y right.

So, you are applying this gradient for a time period time for phase encoding. So, this is the phase that is accumulated. So, you have for each phase we have a baseband signal that you are getting with frequency encoding. So, your s of s 0 of t this t is what, x direction time over which you are acquiring essentially it translates through frequency correct gamma G x t is going to give you the highest frequency in the read out direction, A y is the in the v direction how you are moving in surfaces right.

So, what you have is s naught of t comma frequency and phase essentially right. You have this is the signal f of x comma y e power minus j G x xt e power minus A y d y d x y. So, this is the same equation we saw before and we can readily identify like we said what is your u direction frequency, what is your v direction frequency.

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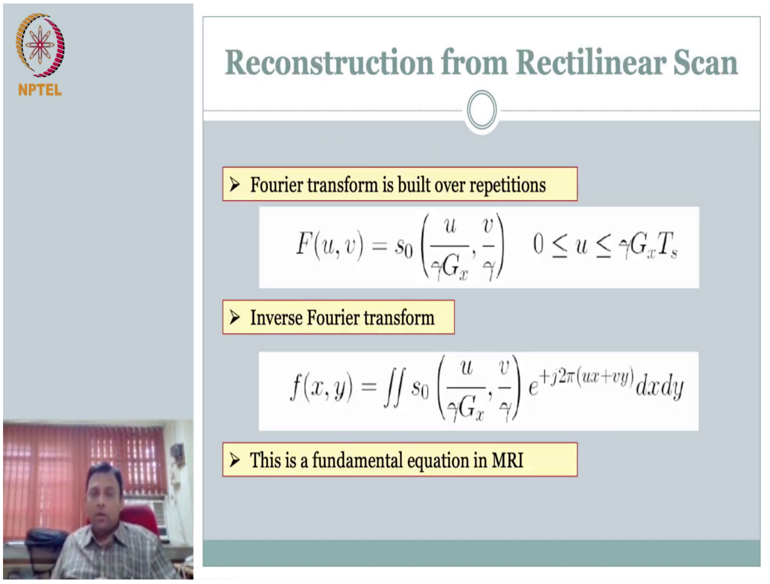

So, once you have this what you essentially have is F of u comma v is nothing but s 0 of u by tau. So, you are reorganizing the data right with this. So, that you recognize what you have in this form is nothing but F of u comma v. So, once you have that take the inverse Fourier transform this is the fundamental equation in MRI or rectilinear scanning. Similarly, what you can do is for your polar coordinates; polar coordinates how do you organize the data you have to have r comma theta or r we will not call r we have been using rho right.

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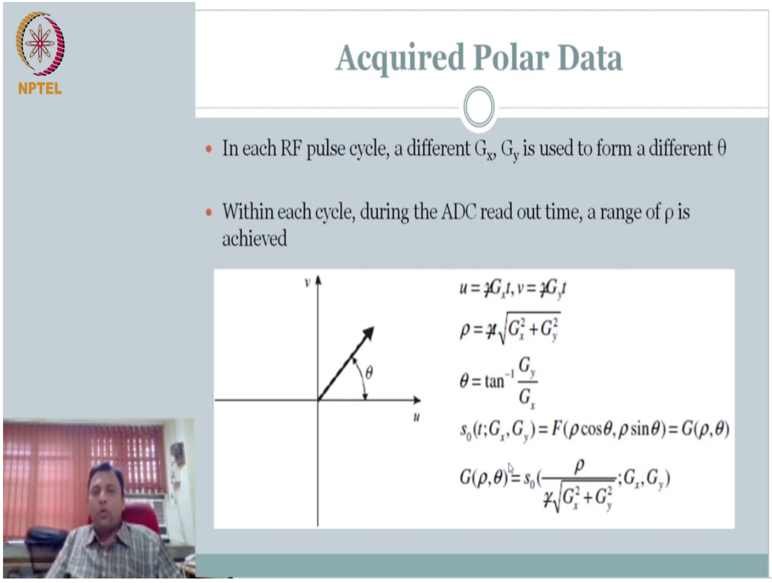

Because so, in the acquired data in the polar coordinate you acquired it with G x G y. So, that you can get different theta. So, range direction we will call it as a rho the angle is theta correct. So, essentially what we are doing here is we are identifying u as gamma G x t and v as gamma G y t we are applying simultaneously G x and G y and the readout is for the same duration.

So, here you notice v also has the t, if you understand the meaning you do not have to pay attention in remembering all this. This will just this will come straight forward by thinking about the physics using the mathematical notations you will arrive at the equations.

So, u is gamma G x t because it is a frequency gamma G y is the frequency you are acquiring it over a period t right t is the acquisition. So, you are having this readout gradient while you are acquiring. So, that is why this t is there. So, this was there from before. The phase direction also in polar means you are applying gradient G y also simultaneously therefore, the t is here also.

So, your rho is magnitude right square root of G x square plus G y square theta is as before tan inverse of these two. So, you have reorganized you recognize what you are measuring it is nothing but it is in the polar coordinate F of rho cos theta rho sin theta for different rho and theta right.

So, once you have this you can go to the time spatial domain which is your image clear. So, there is nothing more to add to image reconstruction with respect to MRI. If you understood the basic signal we are already having Fourier domain of the data 2D Fourier transform of the data take inversely. So, you organize it like this.

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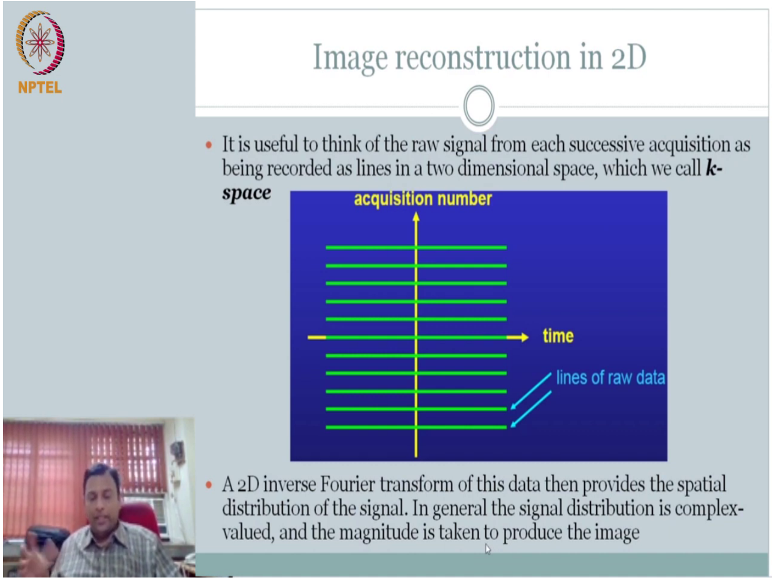

So, how do we generally organized is. So, it is useful to think whatever you are recording the raw signal raw signal from each successively acquisition. So, you have one setting you acquire ones you have another setting you have acquire again right. So, you can label the readout direction is t. So, each acquisition has a time.

So, you can think about your use field different acquisition means you are moving in space in the v direction. So, you can start to think about raw signal from successive acquisition as being recorded as lines in 2D space, that is in case of you know rectilinear for example, it is easy to think about it as parallel lines right. So, we call this as k space I remember that we mentioned. So, Fourier space.

But, in the domain usually they instead of talking about frequency right when you have cycles per second in time is frequency correct or number of cycles you know in 2 pi radians. But, when you talk about spatial variations not time variations usually it is advantageous to say number of cycles over a length rather than time right.

So, number of cycles one cycle is a lambda right in your time domain you know frequency. So, number of lambdas in the length 2 pi length is usually a wave number. So, it is convenient when you talk about spatial frequencies people talk about frequency in terms of k space, k is referring to the wave number ok.

So, that jargon is still there. So, people, but the way we have covered your u is k x, v is k y ok. So, you just have to be careful whatever we are covering is correct you just have to if you are reading different literature from different background they may call this as k space essentially k space it is similar to what you have.

Just denoting it as k space because of the jargon of wave number rather than the frequency. So, you align your data time is your u direction, acquisition number is your y, each time you acquire you align the data like this in your variable. So, this is your Fourier 2D Fourier transform of the data, once you have this you grid it take the inverse Fourier transform ok.

So, you can get your of course, the 2D inverse Fourier transform data provides spatial distribution rate. Generally, it is a complex value and therefore, magnitude is taken to provide the image clear. So, that is it for image reconstruction very simple right you know intuitively what it is by now.

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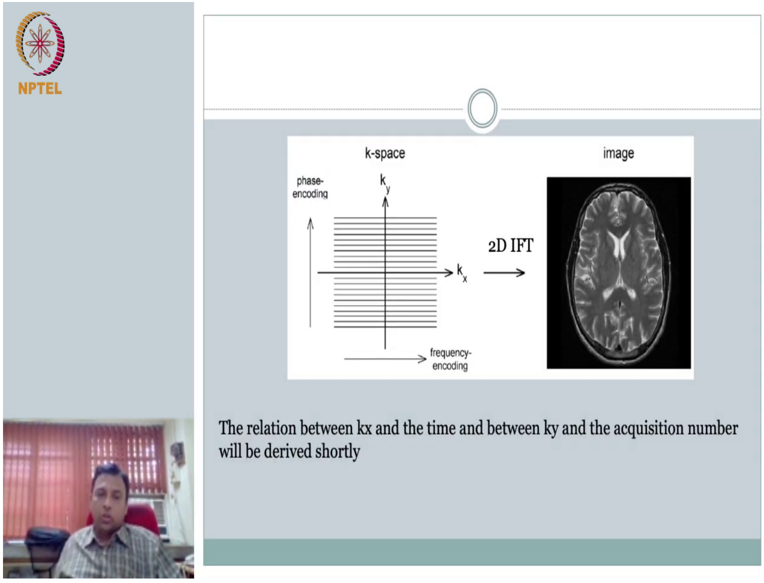

So, just to show another example right what we recorded. So, this is called as k space nothing different from u and v that we covered. One is your frequency encoding direction, the other is phase encoding direction. Whatever you are recording you align it like this in the variable space right, when you align it like this in your variable space and then take 2D inverse Fourier; inverse 2D Fourier transform that should be a inverse.

If you do that you get the image clearly you can see this is fantastic image, but it is really complex to visualize that it was coming from this data acquisition and this data alignment. But, such is the you know beauty of MRI that you can do several things. But, to get this basic feel for what is this gray, what is this black, what does this mean it is not straight forward I hope you repeat the physics lectures and then repeat the data acquisition lectures and get a feel for.

Because reconstruction lecture is straight forward if you understand this taking inverse Fourier transform coming here should not be that difficult to understand ok. So finally, last slide what we will do is put every signal right we have measured all the signal we will put it in the equation align it up. So, that we see the signal equation.

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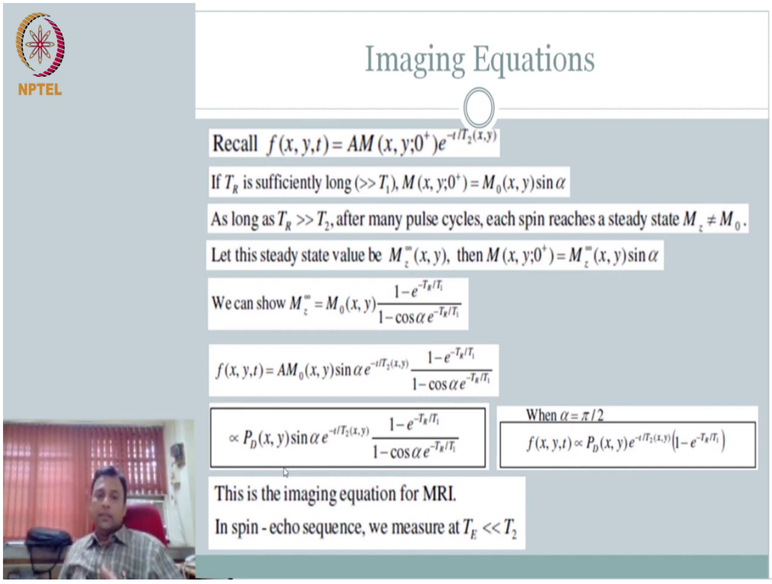

So, imaging equations we know f of x comma y of t is this guy some scaling constants is essentially a magnetization vector from x comma y at 0 plus right at the start, which is going to decay. So, this is your signal that you are recording right in the transverse plane right so, minus t and with time constant here.

But, if T R is sufficiently large which we saw before then no issues this essentially becomes your M naught that is your equilibrium value time sin alpha. But, notice here this is good whatever we have covered so far is good when you do it once. There is an important concept that we will reveal now ok.

What we want to do is repeat it again and again and again right that is this is your magnetization vector and pushing it to the transverse plane again it comes back, again I am pushing it repeating the experiment with the different settings right. So, when I do it like this what happens is we were used to the term called allow the signal to come back to what; to equilibrium position your M naught right that is what we were doing so far.

So, if you allow it to come to equilibrium we will calling that value as M naught. But, it so happens that if you do this multiple times well that magnetization vector never comes to equilibrium right you have to wait for a long time for it to come to equilibrium, but you repeat it. So, what happens is it does not reaches the equilibrium, but it reaches a steady state.

So, each time you do right this experiment the value that it comes ready before you do the next one we can say that after several renditions of this repeats of this you will call it as steady state M z not M naught. M naught is equilibrium, which happens when you wait for long time without multiple push it comes to equilibrium.

The moment you are going to do this pushing experiment several times repeating the sequence several times you are pushing this vector and as you know every time with any displacements right when you do this dynamics it has to have some steady state you do this multiple times right static dynamics. So, when you try to push this several times you will have reach a steady state that M z is not equilibrium, but it is a steady state.

So now, we will just rewrite our equations to correct for this if you are going to repeat the experiments right repeat the acquisitions. So, let the steady state value we will denote it at M z at infinite comma x comma y. So, we are using this jargon instead of 0 we are putting infinity.

Then what happens is your M x y at 0 plus is not M 0, right, this is what we said before, but now it is M z wherever you are starting M z the steady state value not the equilibrium value.

So, your M naught gets replaced by M z at infinity x comma y sin alpha. So, once we can show that this essentially what this M z is your equilibrium value with some you know deviation.

The deviation has to do with number of times you are repeating and the properties of how long you wait which will dictate your T 1 right. So, T 1 constant T 1 property of the tissue and how far you wait that your T R; this relative T R to T 1 is going to have some deration of your equilibrium value.

So, we are going to end up using M z the steady state value from the imaging equations instead of equilibrium value. And therefore, your f of x comma y of t is nothing but you substitute right you substitute the values you get AM naught x sin alpha e power whatever times this guy right.

So, which we can directly say this M naught was proportional right. So, it can say it is proportional to proton density sin alpha this guy. So, when alpha is also pi by 2 which is your maximum signal then you get f of x comma y is proportional to this guy ok. So, this is your imaging equations this is modified; this is your f of x comma y.

Meaning what is your f of x comma y comma t? This is the image right at every pixel x comma y this is your image at every pixel x comma y your basic signal strength is dependent on the proton density at that location. But, it is also dependent on the T 2's and T 1's and the time to repeat all that is going to.

So, we saw in contrast mechanism right how do you play with this to get a differential weighted images right, that is our f of x comma y comma t this is a governing equation depending on how you combine T 2, T 1, T R you get different weighted images ok. So, of course, in spin echo we measure T E is far far less than T 2 right you repeat the experiment, clear? So, this completes in some sense the image formation.

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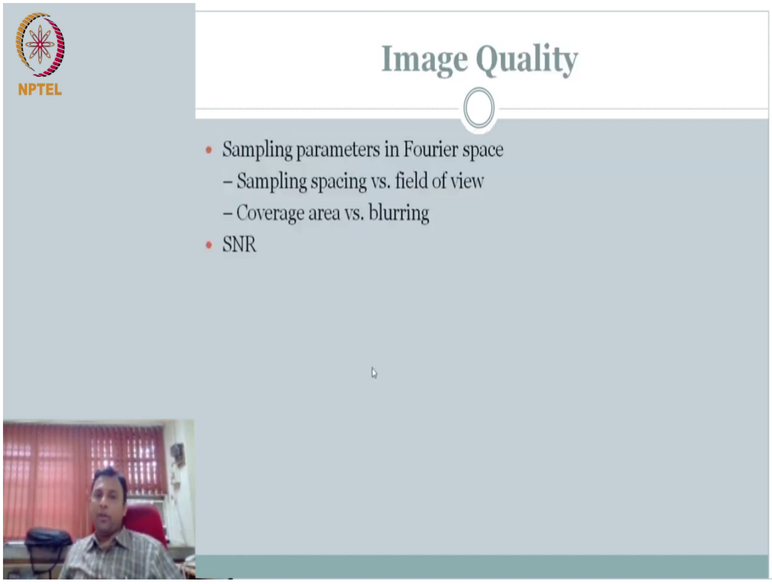

We need to next study about image quality.