Designing of RF Pulse Sequences for Magnetic Resonance Imaging System

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Abstract— Magnetic Resonance Imaging (MRI) is a non invasive medical test which is used by radiologists to diagnose and treat medical conditions. Comprehensive images of the body part/tissue are produced using 1.5 Tesla strong magnetic field and radio frequency pulses. Magnetic Resonance Imaging is based on the principle of changing the magnetization property of the hydrogen atoms in human body by using RF fields. These RF fields are generated using a set of pulses called as pulse sequence. Design of these pulse sequences depend on the imaging application required. In this paper the design method of producing these pulse sequences is explained in detail. Pulse sequence is a sequence of temporal waveforms consisting of RF pulses, gradient (magnetic fields) waveforms and data acquisition intervals. Some of the commonly used pulse sequences are: Spin Echo (SE) sequence, Inversion Recovery (IR) sequence, Gradient Echo (GRE) sequence etc. Using these SE, IR, GRE pulse sequences we get different images like T1 weighted, T2 weighted, proton density (PD) weighted image. These images depend on Repetition Time (TR), Echo Time (TE) and Proton Density (PD) (1). The signal received from hydrogen proton is recorded and then K space is filled. By taking the Inverse Fourier Transform of K space data the image is reconstructed.

Keywords: MRI, TE, PD.

I. INTRODUCTION

An MR image is obtained by acquiring data in steps. The RF pulse excites the tissue magnetization with the help of a slice selection gradient in z dimension. Then frequency encoding and phase encoding are performed to spatially localize the protons in the x and y dimensions.

As the SINC pulses are easy to design and slice profile can be approximated using Fourier transform of the SINC pulse, it is used in the pulse sequence for excitation purpose. In the pulse sequence first slice selection gradient (along Z axis) with RF excitation pulse is applied, so that the specific area of body is selected and excited for further encoding of that part of the body. To encode the selected slice phase and frequency (readout) gradients applied along the Y and X axis respectively. Using this encoded data K space matrix is filled and to get the image of body part, the Inverse Fourier Transform is taken.

Three pulse sequences (SE, IR, GRE) are explained in section II. In section III pulse sequence generator used in MRI scanner is elaborated. In section IV, design procedure of the RF pulse sequences is given and relation between different parameters is also given. Simulation and results of the experiments are shown in section V. Also the 90^0 and 180^0 pulses with gradient waveforms (7) are shown in the simulation diagrams.

Design of GUI in Matlab is explained in this paper. Due to GUI, it is easy to switch between different pulses without concerning the actual code.

In the end, paper concludes with discussing the different pulse sequences has their own important according to the application and the use of forward SLR transform for generating the slice profiles.

II. RF PULSE DESIGN

To get a specific tip angle, first the SINC pulse is designed(6) i.e. its amplitude, duration of the pulse etc. The magnitude of RF pulse for a specific flip angle is given by,

$$B1=\theta/(\gamma * T) \qquad (1)$$

Where, θ - flip angle, γ - gyromagnetic ratio, T - duration of RF excitation pulse. To select the B1 value (i.e. magnetic field value in Tesla and depends on θ), we have to be cautious about SAR. SAR is Specific Absorption Rate of RF power absorbed by the body, it is measured in W/Kg. SAR depends on B0, flip angle and RF bandwidth.

$SAR \propto B0^2 * \theta^2 * \Delta f$

Where, B0 - main magnetic field (1.5T), θ - flip angle, Δf - RF bandwidth. SAR limits for different tissues: Whole body scan: 2W/kg, Head scan: 3.2W/kg (8).

III. GRADIENT WAVEFORM SHAPES

The area of the gradient waveforms or lobes are decided by the imaging parameters like Field Of View(FOV), matrix size, bandwidth etc. Generally the shortest duration lobes are used to minimize the sequence parameters like Repetition Time (TR), Echo Time(TE). For the gradient amplifier that uses the linear ramps, the Trapezoidal and Triangular lobes are used. In this paper the Trapezoidal lobes are used in pulse sequences.

IV. RF PULSE SEQUENCES

In this paper three SE, GRE and IR pulse sequences are designed and simulation results are shown.

A. *Spin Echo Pulse Sequence*

Spin echo(SE) sequence is mostly used in clinical application. The SE sequence consists of the sequence: 90^0 excitation pulse along with slice selection gradient - phase encoding gradient – dephasing lobe - 180^0 pulse with slice selection gradient – readout gradient. 90^0 pulse flips the net magnetization in transverse plane and the magnetization goes through T1,T2 relaxation[2] and net magnetization(M) dephases gradually. After 90^0 pulse the 180^0 RF pulse is applied at TE/2 to rephase all spinning nuclei and the echo signal(MR signal or Free Induction Decay(FID)) is generated at time TE.

Each time with 90^0 and 180^0 pulse the slice selection gradient is applied to get the image of specific body part. Then the phase encoding and frequency encoding gradients are applied to spatially encode the hydrogen nuclei in that body part. Frequency encoding gradient has two lobes with same positive polarity, one is prephase and other is readout gradient. Dephasing lobe is applied so that the echo signal is acquired at later time.

The SE sequence can generate T1, T2 weighted images depends on the TR and TE time. With short TR and short TE the T1 weighted image can be generated. To get the T2 weighted image the TR and TE both should be long. The PD weighted image is obtained using long TR and short TE.

The advantage of SE sequence is that it gives the strong signal and fewer artifacts. It produces good contrast images. Although the scan time of the SE sequence is large, this sequence is widely used for medical devices.

B. Gradient Echo Pulse Sequence

The GRE sequence has one 90^0 excitation pulse doing same function as in SE sequence. Instead of 180^0 pulse for refocusing GRE has negative lobe before readout gradient is applied. After that the echo signal is recorded during readout gradient. The phase and frequency encoding gradients do the same function as explained in the SE sequence. Contrast of images (3) depends on Flip Angle(FA) and TE. High FA and short TE gives the T1weighted contrast, medium FA and short TE gives the PD weighted contrast and low FA and long TE produces the T2 weighted contrast. The scan time of the GRE images is less as compared to the SE images. It has less RF deposition to the body as it requires one RF(90^0) pulse only.

C. Inversion Recovery Pulse Sequence

IR sequence consists of one 180^0 RF pulse which takes the net magnetization to -Mz axis(4). There is only T1 recovery going on because there is no magnetization in the transverse plane. The T1 recovery continues for some time which is called as Inversion Time(TI)(2). Then the normal sequence either SE or GRE is applied to obtain the image. The IR sequence generally has large TR and short TE that's why the contrast of the image entirely depends on the inversion time. Normally the TI in the range of 400-700 ms is used for T1 weighted contrast images.

V. PROPOSED WORK

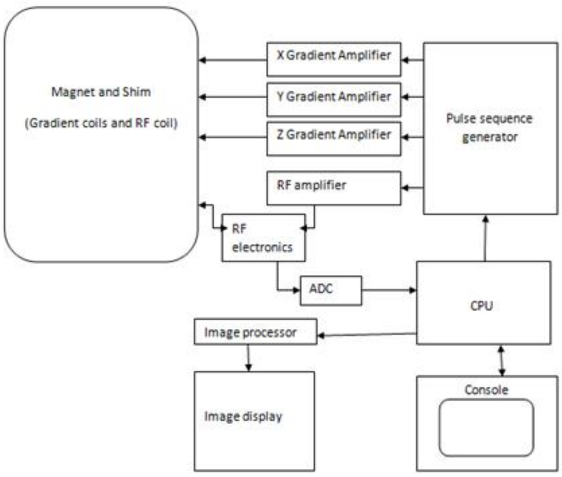

Fig. 1: Block Diagram of Mri Imaging System

The waveform generator (pulse sequencer) designed to generate the pulse sequences according to the program and these pulses are given as a input to the gradient amplifiers and RF amplifier. The gradient amplifiers work as per the pulses applied to them. According to the type of image required (e.g. T1 weighting, T2 weighting, proton density weighting etc.), the pulse sequence parameters can be changed. Fig.1 shows the block diagram of the MRI scanner with pulse sequence generator.

The signal received from the coils is given to the ADC for further processing during read out gradient. According to the received signal phase and frequency, the k space (5) is filled and then by taking the inverse Fourier transform the image is reconstructed.

VI. SIMULATION AND RESULTS

The duration of the 90^0 and 180^0 RF pulse is taken as 150 sec. According to the flip angle and duration of the pulse the magnitude of the RF pulse is calculated from equation (1). The other specifications are taken as: FOV=15 cm, Nx=Ny=256, TBW=4, slice thickness=5 mm, maximum gradient amplitude=33 mT/m. The magnitude of 90^0 and 180^0 RF pulse obtained as 39.15 µT and 78.29 µT respectively.

The SE sequence is shown in Fig.2, first 90^0 RF pulse is applied with slice selection gradient, then phase encoding gradient is applied, after that prephase gradient, 180^0 with slice selection and at last readout gradient is applied. Fig.3 shows GRE sequence, first 90^0 RF pulse with slice selection gradient is applied, then phase encoding, then negative lobe of prephase gradient and at last readout gradient is applied.

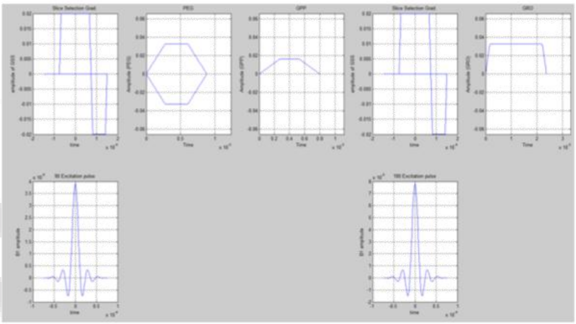

Fig. 2: Spin Echo Pulse Sequence

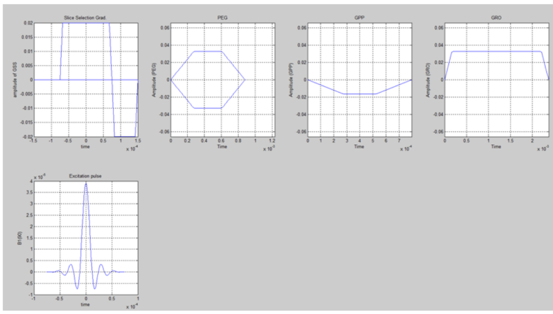

Fig. 3: Gradient Echo Pulse Sequence

Fig.4 shows the Inversion Recovery pulse sequence. In this sequence first the 180^0 pulse is applied , after that we can apply either SE or GRE sequence, in this case the SE sequence is applied after 180^0 pulse.

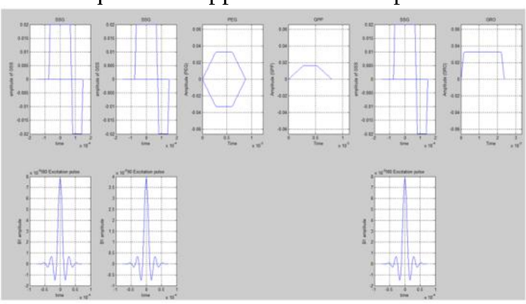

Fig. 4: Inversion Recovery Pulse Sequence

VII. GUI DESIGN

GUI is designed to provide the control over the sequence generator without touching the program. In Matlab, GUI can be created either by programming or by using Guide. In this GUI the pop-up menu is available to switch between different pulse sequences. The sequence will be generated by pressing the push button named ’plot the sequence’, according to the inputs like pulse duration, FOV, slice thickness, time bandwidth product (TBW). Fig.5 shows the GUI created for pulse sequencer, using pop-up menu any sequence can be selected. Also selection of inputs like duration of pulse, slice thickness, FOV, inversion time, TBW are provided in the GUI. And then the sequence is plotted using ’plot the sequence’ button.

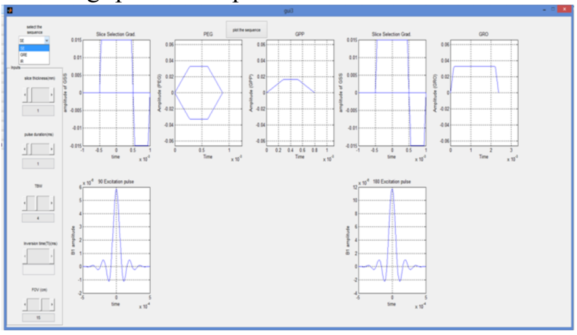

Fig. 5: GUI For Pulse Sequence Generator

VIII. CONCLUSION

The different RF pulse sequences have been generated using Matlab software; also the gradient waveforms are generated. The response(scan time) of the pulse sequences also obtained and compared. The GRE sequence has lesser scan time among these three sequences. The SE pulse sequence is popular and generally used in the imaging. In future, these RF pulse sequences can be generated using SLR algorithm(4) which gives the control to the user over different parameters of the pulse like ripple in stop band and pass band of slice profile.

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