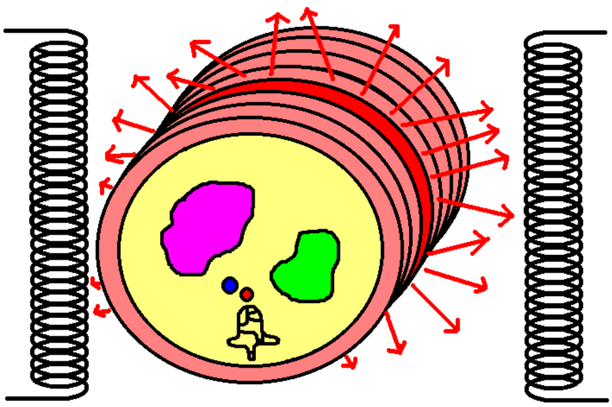
Spatial Encoding
Part 2 – Phase Encoding

Introduction

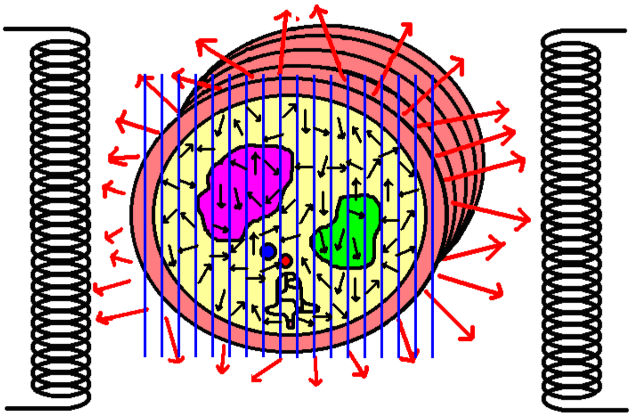
In the last edition of BAMRR News we looked at the first stage of the process of spatial encoding – the process by which signal received in the coils is encoded such that it can be resolved into an image. We used a simple spin echo sequence to examine how slice select gradients are used to excite only one slice at a time, and thereby reduce a 3 dimensional problem down to a 2 dimensional problem. In this article we look at the next step, whereby we start to establish the location of each signal within the excited slices, and the first part of this process is phase encoding.

As before it will be easier to describe the process if we imagine that we are scanning true axial images, however by using alternative gradient coils, or even a combination of all 3, the scanner can of course acquire coronal, sagittal or indeed any obliquity of slice we desire – one of the great selling points of MRI.

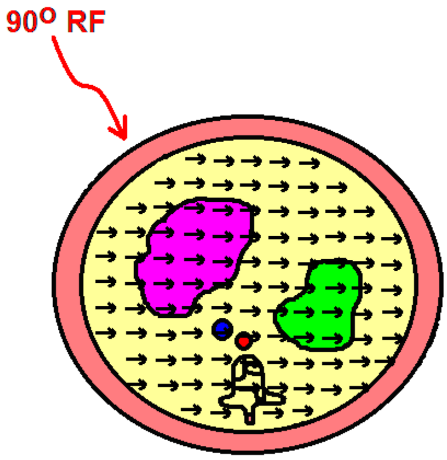


Signals from our excited slice of interest are detected in our receive coils and a current is generated. But in order that an image can be made, it needs to be established from exactly where in this slice each signal has originated. To achieve this, each signal must be in some way ‘tagged’ with this extra spatial information. In our example we are considering an axial image, so if we can gain the x and y coordinates of each signal, then a meaningful and accurate image can be resolved.

The first part of this process will be to reduce things to a one dimensional problem by establishing which column the signal comes from, and this is done by a process called Phase Encoding.

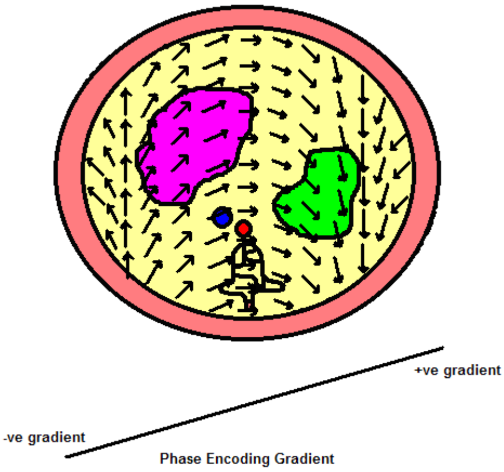


In this example we will use phase encoding to establish which *column* the signals are originating, i.e. where in the x direction of the slice. As an operator you can easily alter this to get the phase encoding process to establish *rows*, i.e. where in the y direction, by swapping the 'Phase Direction' within your scanning parameters. There are several good reasons that you may need to do this and these will be discussed at the end. For now let's stick with using phase encoding to establish the x axis position.



When the initial 90^o RF pulse is introduced to the patient, two important processes occur. Firstly the protons are moved into a higher energy state. This is important to us as this enables them to release energy on removal of the RF as they return to their preferred state of precession, and consequently produce a signal that we can measure. Secondly, they are momentarily all aligned in the same phase of their precessions. Fortunately this phase information is carried within the signal received by the coil, so we can exploit this to enable phase encoding.

To phase encode the protons, just after the 90^o RF pulse has been switched off, a gradient is applied (in our example in the x direction) for just a few milliseconds, then switched off again.



This gradient adds to the main magnetic field such that is becomes momentarily slightly weaker at one side of the imaging plane and stronger at the other. The result is that protons experiencing a higher magnetic field will spin faster than those in the lower field for the period of time that the gradient is on. This causes the once aligned protons to fan out, based on where they are along the phase gradient. Once the gradient is switched off all the protons revert to precessing at the larmor frequency, *but* they will retain the acquired phase shift, and as such they will be phase encoded, i.e. protons *within* each column will share the same phase, but across the patient each column will differ in phase from the others in a predictable way. Therefore, by considering the phase of a signal measured in the receive coil, the scanner is able to establish from which column of the patient it originated.
The net result of this is that, for example, if a signal is measured with phase  then you would be able to say that is must have originated from somewhere in the 5th column from the left in the diagram, however without more information you cannot yet tell from which row. Once we have this information, then we could fully resolve the location of this signal and use it to form an image, but for this we need to turn to the final process of spatial encoding which will be covered next time in part 3.

Phase Encoding and Scan Time

With a simple spin echo sequence a single TR produces one phase encoding step and therefore fills one line of k space. Multiple TRs need to be repeated for each line of resolution chosen.

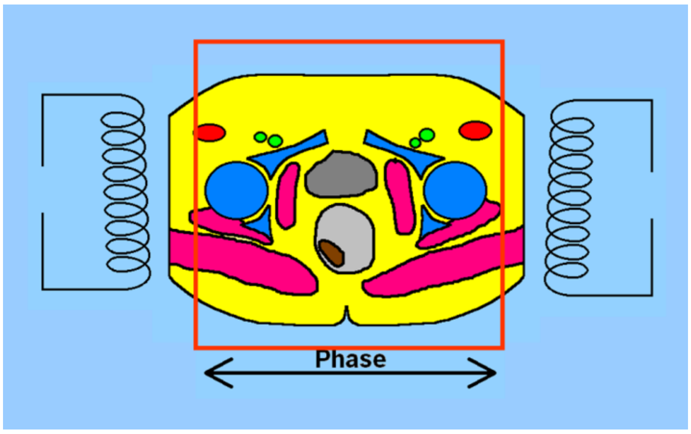
Higher phase resolution = more phase encodings
More phase encodings = higher number of TRs
Higher number of TRs = More lines of k space to be filled
More lines of k space to be filled = Longer scan time

Therefore your chosen image resolution in the phase direction α Scan time.

With fast spin echo, several lines of k space are filled in each TR, and so scan times can be significantly reduced.

To help keep scan times low, the phase and frequency directions are usually chosen so that phase encoding covers the narrowest part of the patient's anatomy wherever possible. This technique will therefore keep scan the time as short as possible as increasing frequency encoding does not affect scan time. This will be discussed further in the next issue.

Phase Wrap



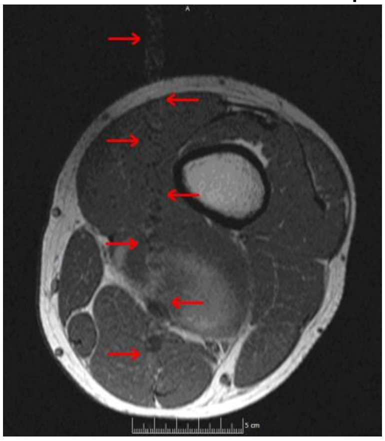
If the field of view coverage in the phase direction is close to (or even within) the patient's anatomy (red box in the diagram), there is a good chance that phase wrap will occur. This is because despite this tissue being outside of the field of view and hence area of interest, it will still have received excitation and phase encoding. The phase these areas are put into will match areas of interest on the other side of the patient in the phase direction, and therefore the scanner software merely follows the encoding rules and maps them into the image where it believes they belong. There are several options to prevent phase wrap. Ensuring the field of view is larger than the anatomy in the phase direction is one option, which may involve swapping the phase and frequency direction as described above. Another option is to use pre-saturation bands to obliterate the areas of anatomy that may wrap, such that when they do, they produce no signal. Probably the most common option is to add phase oversampling or anti-aliasing into the sequence. This adds phase encodings beyond the field of view in the phase direction to ensure any phase wrap occurs in areas that will ultimately lie outside of the field of view and not be seen. This does however increase the overall scan time.

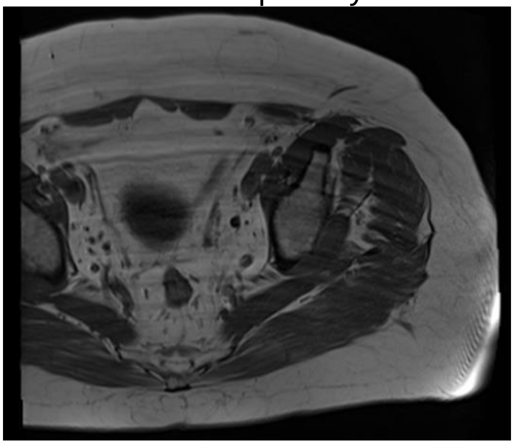
Parallel Imaging

Parallel imaging is used extensively in modern MRI to help reduce scan times. The field of view in the phase direction is purposely reduced to keep the number of phase encodings (and hence scan time) to a minimum. As we have just considered, this would normally result in phase wrap, but by use of a short reference scan before the main acquisition, the scanner can determine which tissue is real and which is wrapped, and eliminate the unwanted signals from the image.

Phase Mismapping

Some anatomy is prone to movement, e.g. the anterior abdomen from respiration, the beating heart, peristaltic bowel, CSF flow or flow in a vessel. Where anatomy moves between application of the phase encoding gradients it can be mismapped into the final image and artefacts occur such as the popliteal flow artefact, or multiple anterior abdomen respiratory artefacts..





Sometimes swapping the phase and frequency encoding directions can help. Whilst it will not eliminate the artefact, it can project it into a less obtrusive location. Saturation bands can also be placed over moving anatomy outside of the area of interest. This is a vast subject and will therefore not be covered in any further detail in this article.

3D Imaging

With 3D sequences, the whole volume of interest within the patient is excited at the same time, i.e. the process of slice selection described in the last issue does not take place. Instead, slice selection is performed with a second phase encoding step. Because of this, aliasing is also able to occur in the slice direction which is known as slice-wrap. This can be seen in the first few and last few slices of a 3D volume. It can be eliminated by adding some slice oversampling, at the cost of a small amount of scan time.

In the next part, the final of three, we will consider Frequency Encoding.