# Images That Are Easy To Process:
# Managing Noise and Artifacts in MR Imaging

**R Mark Henkelman** **University of Toronto**

Objectives of the Lecture:

1. To understand how MR images are formed; particularly how the signal is spatially differentiated.

2. To understand how noise is added to MR images and how it appears in magnitude images.

3. To compare noise in MR images to noise in other medical images and to appreciate the need for an "optimal" resolution in MR.

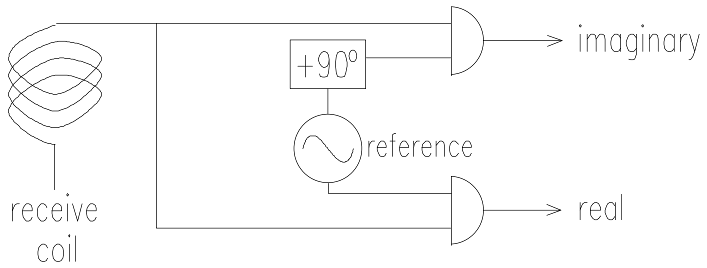
4. To recognize a variety of artifacts that occur in MR images and that make image processing and analysis more difficult. To learn solutions to these artifacts where possible.

**MR Imaging**

- MR images detect time varying voltages induced in a receiver coil by nuclear magnetic moments (usually $H^3$ nuclei) that precess at frequencies proportional to an applied magnetic field. (At a typical imaging field of 1.5 Tesla, the frequency is 63 MHz)

- In an ideal patient (no susceptibility effects, only water) and a homogeneous magnetic field, all spins would precess with a single frequency and the only information that could be obtained would be the total number of precessing spins (an upper bound for the integrated signal in the image).

- All the spatial information is encoded in the amplitude and frequency modulation of the received signal which is typically contained within a bandwidth of ± several KHz about the precessional frequency. This imaging information is detected by quadrature demodulation of the receiver coil voltage. The demodulated signal may be then represented as:
  - i) A real and imaginary time series
  - or ii) A magnitude and phase time series




- The spatial information is encoded in the signal using some combination of 3 encoding schemes generated by magnetic field gradients.
  1) Frequency encoding (read out)
  2) Phase encoding
  3) Excitation encoding (slice selection)

- The acquired data is converted to image data by a 2 or 3 dimensional Fourier Transform. Thus the spacing between acquired data points determines the field of view (FOV) of the image and the range of the acquired data determines the number of pixels across the image.

**Noise in MR**

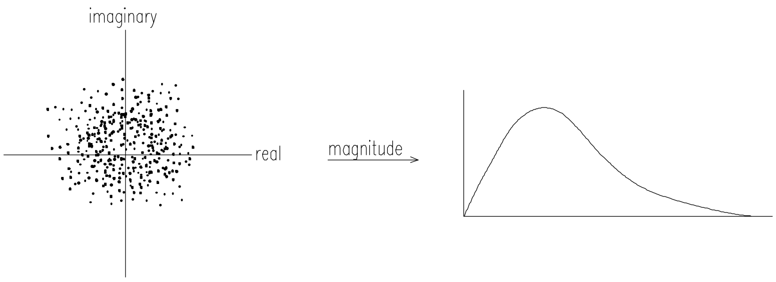
- Noise in MR image data comes from random electronic noise in the coil and its assorted electronics, or in high field imaging systems from thermal magnetic fluctuations from the patient picked up by the receiver coil. These could be eliminated by cooling the patient, but this does not represent a practical solution.

- The noise on the raw data is complex, random, Gaussian and white and thus Fourier transforms into image noise which is also complex, Gaussian and stationary. Although noise appears at specific locations in the image, it does not come from any particular location in the object.

- Noise can be reduced by averaging N times. Since the image signal is coherent, it scales as N; but the noise is random, so scales as $\sqrt{N}$. Therefore, with N averages, the signal to noise ratio (SNR) scales as $\sqrt{N}$. If each dimension of a voxel is reduced by 2x (i.e. the volume is reduced by 8x) and hence the signal per voxel is reduced by 8x, the SNR per voxel can only be recovered by averaging 64 times.

- In practical MR imaging, signal and noise are given properties of the patient and imaging coil, and acquisition time is restricted by practical throughput considerations. Thus the resolution is chosen to achieve a reasonable SNR per pixel. For visual interpretations, a SNR of 15 seems optimal. Higher SNR should be spent to obtain better resolution. Lower SNR rapidly degenerates into "salt and pepper" images which are uninterpretable. Rebinning to recover SNR wastes image acquisition time. It is better to choose an optimal resolution prior to acquisition.

- Because the phase in MR images is frequently meaningless, MR images are often displayed as magnitude images. Under the magnitude operation, background noise which is bivariate normally distributed in the complex plane, becomes Rayleigh distributed.




If $\sigma$ is the standard deviation of the complex noise, the mean of magnitude noise is $1.253\sigma$ and the standard deviation is $0.665\sigma$. Noise in a region of uniform signal intensity still is normally distributed after processing with the magnitude operator.

- Detectability in MR images depends on the signal difference to Noise ratio ($\Omega$SNR). Contrast to Noise Ratio (CNR) which is used in photon limited imaging methods such as X-ray and PET, has no meaning in MR images.

**Artifacts in MR Images**

In spite of continuous improvements in MR hardware and imaging software, there are still structures that appear in MR images that do not correspond to any structure in the object being imaged. Such unwanted structures are called artifacts. Often, such artifacts can be circumvented by making changes in the method of image acquisition or reconstruction. It is always easier to eliminate artifacts at their source than it is to post process around them.

This section lists a variety of MR imaging artifacts and identifies ways to eliminate them.

Aliasing Artifacts

- – image intensity that extends beyond one boundary of image and reappears into the opposite boundary.
- over sample in the aliased direction
- selectively saturate the aliased intensity
- only excite within the imaging volume

Truneation Artifacts

- – oscillating intensity bands propagation from an image signal discontinuity
- roll off the high frequency data smoothly to zero
- sample farther out in data space
- median filter the image with an edge conserving filter

Oscillating wave amplitude across the image

- correct the discrete erroneous point in the raw data by deletion and interpolation

Discrete noise lines in the phase encode direction

- eliminate sources of rf interface
- check rf shielding (particularly the door)

Susceptibility Artifacts

- – regions of signal loss around patient magnetic discontinuities
- acquire higher spatial resolution
- use shorter echo times
- is spin echo imaging

Chemical Shift Artifact

- – dark and bright boundaries at the edges of fatty regions
- use fat saturation or Dixon type fat suppression

Field Distortion

- – the image of a rectangular grid is not rectangular
- use image warping software (make sure intensities are sealed correctly)

Eddy Current Artifacts

- – -there are many manifestations including interference fringes
- confirm the eddy current compensation
- use ancillary gradients to spoil stimulated echoes
- space out gradient waveforms in the acquisition

Patient motion and flow ghosts

- restrain patient motion
- use motion compensated sequences (gradient moment nulling)
- saturate spins in unneeded parts of the object
- use gating and triggering
- use active monitoring of motion and image tracking
- use variance suppression schemes to replace bad data

Non Uniform intensity (from rf excitation)

- use body coil excite
- use adiabatic excitation pulses
- use multiple tip angle excitations

Non Uniform intensity (from receiver coils)

- use a larger volume receiver or phased arrays
- correct for coil sensitivity (noise is no longer uniform)

Signal intensity between slices

- check method of signal intensity variation
- do interleaved acquisitions
- increase gaps between slices

**Conclusion**

The image that is best for analysis, segmentation or post processing is not necessarily the best diagnostic image!