Nuclear Associates 76-903

MRI Multi-Purpose Phantom

Users Manual

March 2005
Manual No. 76-903-1 Rev. 2

Fluke Biomedical
Radiation Management Services

6045 Cochran Road
Cleveland, Ohio 44139
440.498.2564

www.flukebiomedical.com/rms

Table of Contents

(Blank Page)

Section 1
Introduction

1.1 Introduction

This phantom is designed for comprehensive evaluation of critical imaging parameters of magnetic resonance imaging (MRI) in a time efficient manner. Particular attention was paid to obtaining all the necessary image quality information with a minimum number of imaging sequences. It is designed to study parameters unique to multi-slice two-dimensional and three-dimensional Fourier imaging.

The overall dimensions of the phantom adjust so that it can be positioned in each of the three major imaging planes: axial, coronal and sagittal.

The phantom can be used for the measurement of absolute values for calibration purposes. However, its design is optimized for time efficient daily quality assurance.

The performance parameters that can be evaluated using the phantom include: slice orientation, slice thickness, interslice distance, aspect ratio, magnetic field uniformity, radio-frequency signal uniformity, spatial resolution, T_1 and T_2 values, and modulation transfer function. The phantom can also be used to evaluate such parameters as resonant frequency, radio frequency power setting, radio frequency quadrature setting, magnetic field gradient calibration, slice off-set parameters, image off-set, and other image artifacts peculiar to MRI.

1.2 Orientation Imaging Method

In a two-dimensional Fourier transform (2DFT) imaging of MRI, the data is collected in two orthogonal directions, i.e., encoding and readout.

In some imaging sequences, the spatial resolution may be different in the two directions. The star pattern is designed to study such asymmetric resolution as well as qualitative modulation transfer function (MTF) in MR images. For this reason, it is important to properly orient the star pattern. Note four lines or dots on the wall of the phantom.

Place the phantom in the imaging system so that one is in either the phase encoding or frequency readout direction.

1.3 Choosing Echo Time

Any clinical multi-slice imaging sequence can be used. Often, however, the imaging sequences with the shortest echo time (TE), largest number of slices possible within the pulse repetition time (TR), and single excitation (no averaging) will demonstrate the performance of an imaging system under one of the most demanding situations. For a daily QA program, it is important to record all the important imaging parameters. An example of such a table of imaging parameters can be found in Table 1-1.

1.4 NMR Solution

Any NMR signal-producing solution can be used to fill the phantom. It is desirable to use solutions with T_1 and T_2 values around 500 - 1000 sec, because it can better simulate the clinical imaging conditions. One should note that
T_1 and T_2 values depend on the magnetic field strength.

Filling the phantom requires special care to avoid any trapped air bubbles. Water can be degassed by first boiling and cooling prior to filling. Use of a wetting agent and algicide can also prolong the useful life of the solution. A fairly full phantom can be placed in a vacuum chamber to eliminate the bubbles. One way to avoid the trapped bubbles, especially in small holes, is to fill the holes with solution using a small syringe needle. This may require disassembling the phantom.

Any solution can be used; however, for higher field systems, solutions with chemical shift should be avoided. Copper sulfite or manganese chloride were found to be useful.

A water solution of 0.1 millimolar manganese chloride can be used to fill the phantom. The T_1 value of this solution is approximately 500 msec. A shorter relaxation time is not suggested, as it may not correctly represent the system performance in a realistic clinical environment.

Table 1-1. Summary of Imaging Parameters

Orientation:
Imaging Technique:
TE= Shortest possible
TR=
Number of Slices =
Slice Thickness =
Slice Sequence = Interleaved or others
Slice to Slice Gap =
Number of Encoding = 256, 128 or 64
Signal Averaging = No averaging, single
RF Tuning Parameters (i.e. attenuation settings):

NOTE

For daily QA, exactly same parameters using same pulse sequence should be used.

Section 2
Specifications

2.1 Phantom Design

All of the parts in the phantom are made with plastic and glass, free of magnetic material. The basic design of the phantom is a 9" diameter plexiglass cylindrical container with various inserts filled with an NMR signal producing solution. The phantom is designed to fit inside a head coil. The cylinder has three sections, flood, cone, and insert section (Figure 2-1). The flood section is a typical flood phantom that can be filled with a solution.

Figure 2-1.

The conic section has four concentric cones (Figure 2-2). The concentric conical grooves of 45° are cut from a solid plexiglass block.

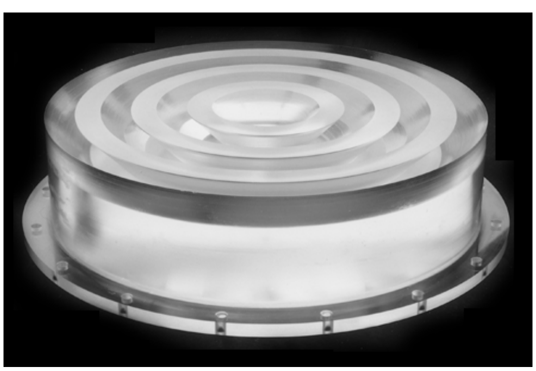

Figure 2-2.

The insert section has six inserts, one 120° star pattern wedge assembly, two folding step wedges, spatial resolution insert, and T_1 and T_2 sample vials (Figure 2-3).

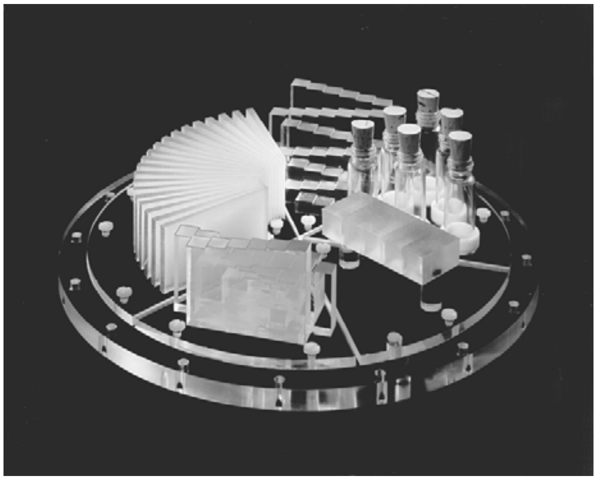

Figure 2-3.

NOTE

Addendum for Model 76-903: MRI Multi-Purpose Phantom: The negative contrast resolution insert (rods), as seen in Figure 2-3 has been discontinued and replaced by a T_1 and T_2 sample vial insert, as described in Figure 3-13.

Section 3
Theory Of Operation

3.1 Omni Directional Application

Since MR images are obtained not only in axial but also sagittal and coronal orientation, the phantom is designed to be placed in all three directions. The selection of inserts, their sizes and arrangements are made to obtain the maximum amount of imaging information in any orientation in a single scan.

3.2 Concentric Conical Rings Section

The concentric conical rings are machined by cutting out a circular groove at an angle of 45°, as shown (Figure 3-1).

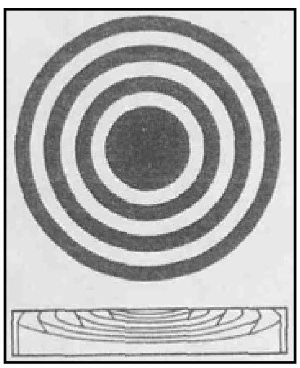

Figure 3-1. Outside diameter, 9, Number of segments, 4

The conical section can provide the following information by simple visual inspection:

- Slice thickness uniformity
- Aspect ratio
- Magnetic field homogeneity

3.2.1 Slice Thickness Uniformity

The dark and light concentric rings in the image represent the slice thickness multiplied by the square root of 2.0 due to the 45° grooves. The width of the rings (bands) should be the same throughout the image for uniform slice thickness. More careful analysis can be carried out by measuring the brightness profiles with region of interest computer routines.

3.2.2 Aspect Ratio

Visual inspection followed by a measurement of the diameter of the outermost ring can provide information on the aspect ratio. The video display should be checked independently to avoid any distortions in the display screen.

Figure 3-2 shows the cross section of the concentric conical part of the phantom. The aspect ratio is correct, as is the uniformity of the slice thickness as represented by the uniform widths of dark and light circular bands.

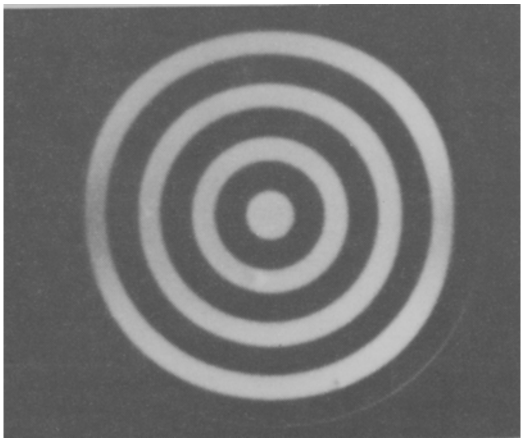

Figure 3-2. Cross Section Image

3.2.3 Magnetic Field Homogeneity

Any distortions in the roundness of the rings can be a result of non-uniformity in the main magnetic field, as shown (Figure 3-3).

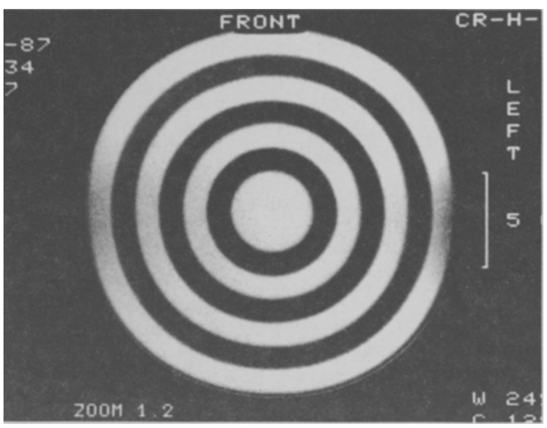

Figure 3-3.

3.3 Flood Section

This section is a typical flood phantom, 9" in diameter by 1.25" thick. It may be filled with any signal producing solution (Figure 3-4).

- RF Signal Uniformity
- Single T_1 and T_2 Values

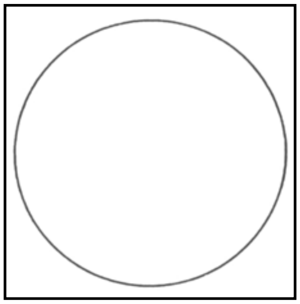

Figure 3-4. Diameter, 9", Depth, 1.25"

3.3.1 RF Uniformity

The flood section is used to measure RF uniformity and to visualize artifacts that can come from many different sources (Figure 3-5).

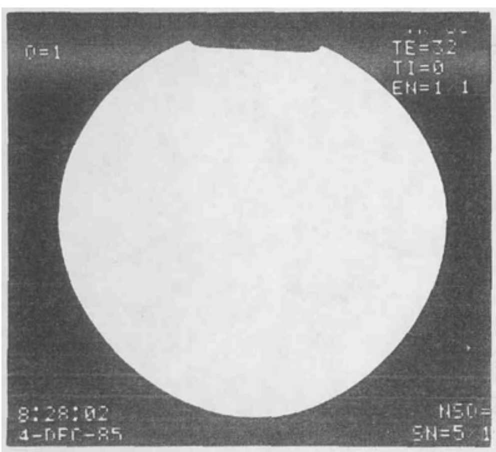

Figure 3-5.

Radio-frequency (brightness) non-uniformity can come from various sources. Most RF coils have a number of active wires and the regions near the wires can show increased signal intensity. It can also come from magnetic field uniformity, eddy current problems and poor RF power setting. RF uniformity can also be affected by internal motion of the solution. One should also look for any aliasing, fold-over or ghosts.

3.3.2 T_1 and T_2 Values

A single value of T_1 and T_2 can be measured using the flood section. It should be pointed out that T_1 and T_2 values depend on magnetic field strength, temperature, imaging sequence, and they are very difficult to measure precisely. Extreme caution should be taken for RF power setting.

An insert with 6 vials is available so that various solutions can be imaged for a range of relaxation values.

3.4 Insert Section

This section has the following inserts:

1. Folded Step Ramps: Slice thickness and slice contiguity (gap), phantom orientation.
2. Resolution Pattern: Square hole pattern for positive contrast.

3. Star Pattern: Modulation transfer function (MTF), horizontal and vertical spatial resolution, quadrature setting and baseline correction.

3.4.1 Folded Step Ramps

Accurate slice thickness measurement in MR is very difficult and various methods are under discussion. The slice profile (shape of slice thickness) is also a very complex subject that needs further discussion and definition by the physics community. This folded ramp approach is adopted in this phantom because of its ease of use and efficiency in time. For a quick evaluation, a simple counting of the number of visible steps will give an estimate of slice thickness in millimeters.

Slice parameters are studied using a pair of folding step wedges. The height of the steps range from 16 mm to
40 mm and the heights vary every 1.0 mm (Figure 3-6). Each step area has a dimension of 10 mm x 10 mm. The wedges were folded to accommodate a greater number of steps in the limited space available. Two inserts of the folded steps are placed at opposite sides of the phantom so that slice orientation with respect to the phantom can be studied.

1. Slice Thickness
2. Slice Orientation
3. Interslice Gap

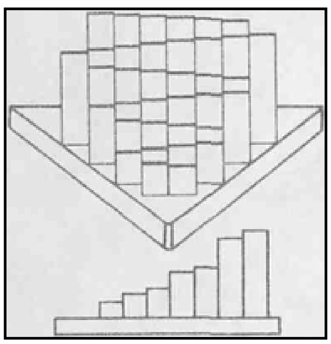

Figure 3-6. Step Interval, 1 mm Range, 36 mm

3.4.2 Fold Step Ramp Analysis

Quick Visual Evaluation

Slice thickness can be evaluated quickly by counting the number of steps that can be visualized at a relatively wide window setting (Figure 3-7). The number of visible steps is equal to the slice thickness in millimeters since the height of each step varies by 1 millimeter. Record the window setting for future reference, for the visible steps vary depending on the window setting.

In Figure 3-7, five gray scale steps can be seen in the 10 o'clock and 5 o'clock positions, representing a slice thickness of 6 mm.

3.4.3 Measurement Method

Better evaluation of slice thickness can be made by using the region of interest (ROI) routine in the imaging system. The area of the region slightly smaller than the step size (10 mm x 10 mm) should be used to read out the signal intensity (NMR number). Than take the difference of the "NMR" number of the adjacent steps. Plot a graph of the difference in intensity on the vertical axis and step sequence numbers on the horizontal axis. The A line graph connecting the dots (diff. vs. step number) represents slice profile and the width of the graph at half of its maximum intensity (full width half maximum) is the measured slice thickness.

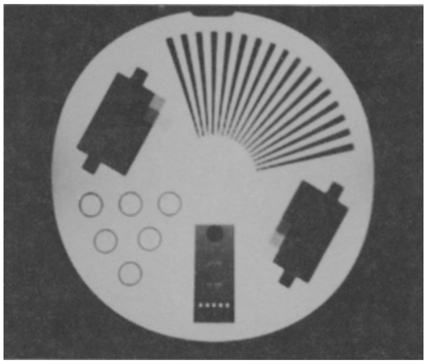

Figure 3-7.

3.4.4 Slice Continuity (Gap)

The slice contiguity can be evaluated by quick visual inspection as well as in a more precise manner. While visualizing the steps of one slice in the image, note the locations of the steps…especially the faint steps. Then, repeat the same procedure viewing the next slice using a preset window. The number of missing steps between the two adjacent images represents the gap in millimeters. It can be observed in Figure 3-7 and Figure 3-8 that two steps are missing between the two slices, representing a 2 mm gap. A more precise measurement can be made by plotting a graph of more than one slice on the same axis.

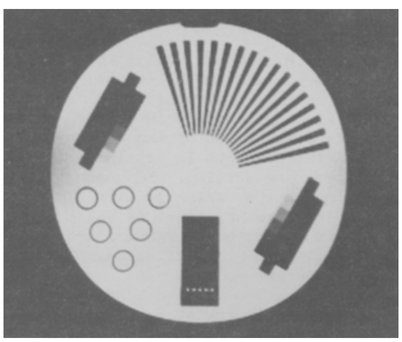

Figure 3-8

3.4.5 Resolution Pattern

Hole Pattern Solution Insert

The resolution insert (Figure 3-9) has 4 sets of square holes (0.5 mm, 0.75 mm, 1 mm and 2 mm machined in an acrylic block. The spacing between the holes is the same as the size of the hole.

In filling the phantom with solution, care must be taken to avoid air bubbles becoming trapped in the holes. This can be accomplished by squirting the solution into the holes using syringes with small needles.

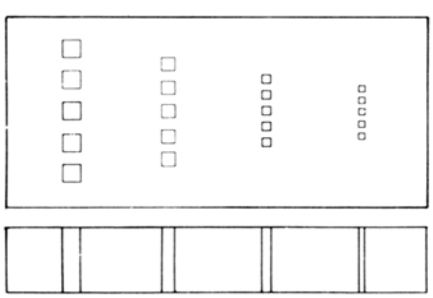

*Figure 3-9. 0.5 mm x 0.5 mm^2, 0.75 mm x 0.75 mm^2, 1.0 mm x 1.0mm^2, and 2.0 mm x 2.0mm^2 square holed.
Five of each dimension. Hole depth, 0.5".*

T_1 and T_2 Solution Insert

This insert (Figure 3-10) holds six (6) 5 cc glass vials (15 mm diameter x 47 mm high) that can hold solutions of varying T_1 and T_2 values. One should note that measured T_1 and T_2 values depend on many parameters including field strength and imaging sequence used.

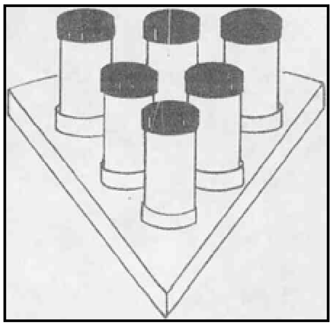

Figure 3-10. T_1, T_2 Solution Insert. Six 5 cc refillable glass vials with caps. (15 mm diameter x 47 mm height.)

3.4.6 Star Pattern

Modulation Transfer Function (MTF)

Modulation transfer function (MTF) is a mathematical concept that provides an objective measurement of the combined effect of image sharpness and resolution. Direct measurement of MTF is often very difficult and calculation of MTF based on measurable parameters such as point-spread function (PSF) or line spread function (LSF) are clearly outside the scope of this manual. Difficult as it may be to have precise mathematical definition, it is however relatively easy to present MTF in a qualitative manner. Similar techniques are used to evaluate x-ray focal spot sizes using a star pattern.

The star pattern developed for this purpose is particularly useful in MR imaging where resolution in vertical and horizontal axes can be different and certain image artifacts that are peculiar to Fourier imaging may not be visible under any other test.

- MTF Evaluation
- Horizontal & Vertical Spatial Resolution
- Quadrature Setting
- Baseline Correction

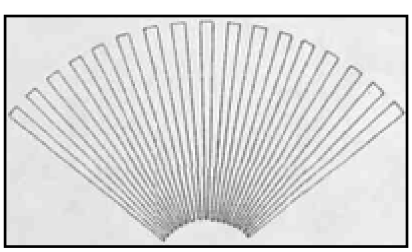

Figure 3-11. Wedge angle, 3°. Number of wedges, 9. Fan angle, 60°. Wedge length, 3". Width, 2".

The star pattern for MTF evaluation is made up of 3° wedges placed on a 60° fan angle. Each wedge is 3” in the radial dimension and 2” in height. Two such sections are placed next to each other to cover an overall fan angle of 120° (Figure 3-11).

A star pattern is a very useful way to measure the many subtle image artifacts that are unique to NMR imaging. It may be difficult to pinpoint the exact source of the artifacts, but this is a powerful test to demonstrate image artifacts that are otherwise difficult to detect.

Horizontal and Vertical Spatial Resolution

One can also observe asymmetric image resolution between the encoding and readout direction by observing the resolving power in the star pattern (Figure 3-12). It can be seen that the vertical resolution is superior to the horizontal resolution by observing that the narrow ends of the star pattern are better resolved in the vertical direction.

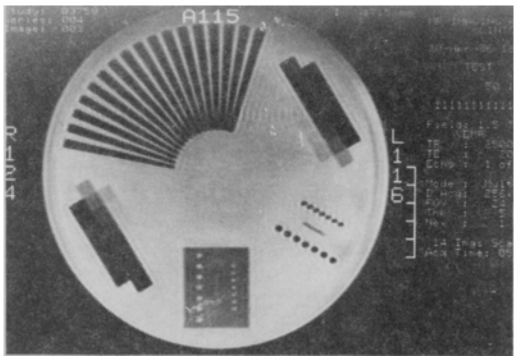

Figure 3-12.

Quadrature Setting

In Figure 3-13, one can visualize a faint star-like pattern in the central 12 o'clock to 5 o'clock position. The star-like ghost pattern is in the opposite orientation of the real star pattern image. This is attributable to the quadrature setting. In quadrature signal detection, which is widely used in MR imaging, the RF signal is split into two orthogonal signals (real and imaginary) before digitization. If the phase angle between the real and imaginary components is not 90°, a ghost of point symmetry appears along the diagonal axis between the encoding and readout directions. This artifact also shows up as a "fold-over" in the star pattern.

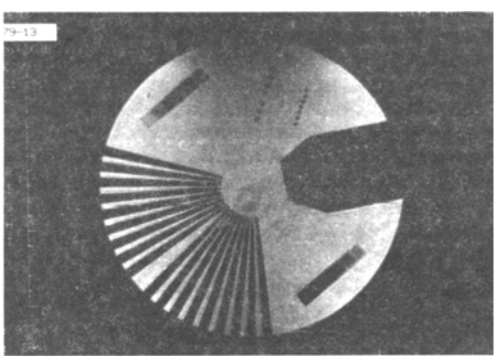

Figure 3-13.

Fluke Biomedical
Radiation Management Services

6045 Cochran Road
Cleveland, Ohio 44139
440.498.2564

www.flukebiomedical.com/rms