

# Cylindrical Encoding in MRI

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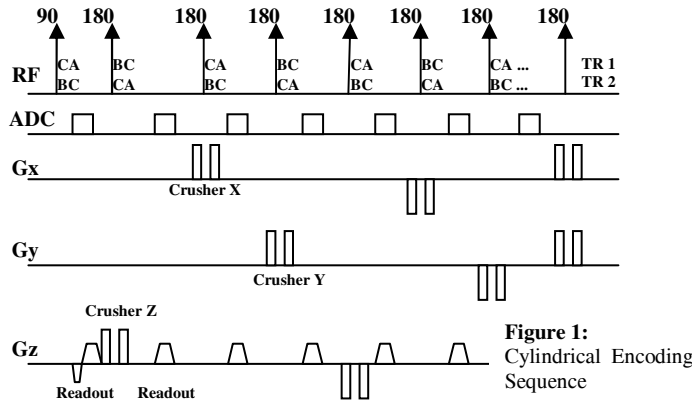
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**Target Audience:** Researchers who are working on interventional magnetic resonance imaging (MRI) applications and novel encoding techniques

**Purpose:** As a medical diagnostic tool, MRI offers many advantages over other imaging schemes because of its non-invasive and non-destructive nature, and good precision level. However, obtaining high resolution images with conventional systems can be done by using expensive high strength gradient systems whose maximum gradient strength is restricted by the nerve stimulation threshold.

In this work, the concept of cylindrical encoding [1] as a novel method for high resolution imaging without requiring the use of high strength gradients is introduced.

**Methods:** The cylindrical encoding is based on the distinct field distribution characteristics of a loopless catheter antenna (CA) [2] and a birdcage coil (BC) in terms of both amplitude and phase. The CA creates a phase distribution according to the circumferential position of the spins. The BC creates a linear phase distribution which is independent of position. The encoding is realized by using a two shot fast spin echo sequence as in Figure 1. The TR is 2.25 seconds. Matrix has a size of 36x256. Echo train length is 18 and echo spacings are 10 and 18ms because of the difference in the RF pulse durations. The RF pulses are transmitted from BC and CA in alternating order. The pulses from the catheter antenna are adiabatic BIR-4 pulses [3] to obtain accurate 90° and 180° flip angle. The duration of each adiabatic pulse is 9.6ms to achieve the adiabatic condition. The pulses from the birdcage coil are rectangular. The crusher gradients prevent undesired echoes. The number and the direction of the crusher gradients change during the sequence. The readout is done in the direction of the main magnetic field. The MR signal is received only by the CA as the radial projection of the spins in the adiabatic excitation depth which is around 2mm according to the Bloch-Siegert shift B1 map measurements. The distribution of magnetization after each encoding step is summarized in Table-1.



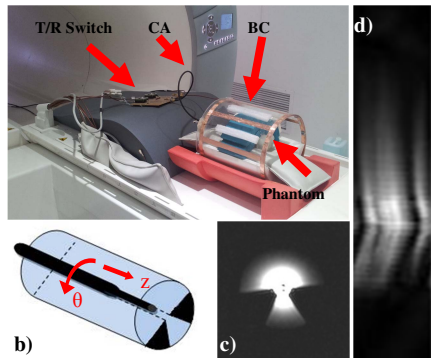
SEQUENCE	TR	COIL	PULSE	SPIN PHASE	MR SIGNAL
		CA	90°	$M_0 e^{(j\theta)}$	$M_0$
TR 1	BC	BC	180°	$M_0 e^{(j\theta)}$	$M_0 e^{(j2\theta)}$
		CA	180°	$M_0 e^{(j3\theta)}$	$M_0 e^{(j2\theta)}$
		BC	180°	$M_0 e^{(j3\theta)}$	$M_0 e^{(j4\theta)}$
		CA	180°	$M_0 e^{(j5\theta)}$	$M_0 e^{(j4\theta)}$
		Continued for total 18 pulses			
		BC	90°	$M_0$	$M_0 e^{(j\theta)}$
	CA	CA	180°	$M_0 e^{(j2\theta)}$	$M_0 e^{(j\theta)}$
		BC	180°	$M_0 e^{(j2\theta)}$	$M_0 e^{(j3\theta)}$
		CA	180°	$M_0 e^{(j4\theta)}$	$M_0 e^{(j3\theta)}$
		BC	180°	$M_0 e^{(j4\theta)}$	$M_0 e^{(j5\theta)}$
		Continued for total 18 pulses			
	BC	BC	180°	$M_0 e^{(j4\theta)}$	$M_0 e^{(j5\theta)}$

**Table 1:** The spin phase distributions of the cylindrical encoding sequence. Spin phase is the phase of the transverse component of the spin at angular position 'θ'. BC creates no angular dependence. RF field created by CA adds 'θ' to phase. Implication of these is summarized in the table.

The BC is an 8-rung high-pass birdcage coil with 19cm diameter and 20cm height. The CA is a 55cm double shielded nonmagnetic coaxial cable with a whip of 1.5cm length and 3mm diameter is attached to the distal end. Moreover, a bazooka balun is placed around the CA for proper operation and better isolation. The experiment setup and coils are shown in Figure 2a. The phantom is a copper sulfate/salt solution (2g CuSO<sub>4</sub>+1g NaCl per 1000g H<sub>2</sub>O) in a cylinder of 3cm diameter and 11cm length with two wedge shape regions. The CA is placed in the middle of the phantom as in Figure 2b. The cross section of the phantom is given in Figure 2c

**Results:** The CA is used in transmit-receive (T/R) configuration via a T/R switch of 27dB isolation. The BC coil is driven in linear mode for only transmission. The CA is placed at the center of the BC along the main magnetic field to minimize coupling that is 32dB. The experiments are done by Siemens TIM Trio 3T Scanner with 8x8kW transmit array system. The applied peak voltage from the CA is 90V that is not optimized for minimum SAR and the applied peak voltage from the BC is 30V.

The cylindrically encoded k space is rearranged according to the encoding step of each acquired raw data and the images are obtained through the inverse Fourier transform of the rearranged k space. The reconstructed image is shown in Figure 2d in which the horizontal axis is the circumferential direction and the vertical axis is the z direction.



**Figure 2:** a) experiment setup b) phantom c) axial phantom image d) cylindrically encoded image. Vertical direction is along CA (top of the image is the proximal end of CA), horizontal direction is the circumference of CA

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**Discussion:** Intensity variation along the vertical direction is due to sensitivity variation along the length of the catheter. The two dark regions correspond to the two wedges of the phantom. Although the circumferential position of the wedge has no variation along the length of phantom, a variation can be seen in the image. This may be due to phase change along the length of the CA. Moreover, although the CA is placed along the z direction, the encoding can be done as the CA directed in any other direction with the cost of some distortion in the image. These effects may be corrected using post-processing techniques.

This method achieves encoding only in circumferential and z directions. Therefore image in Figure 2d is a projection imaging along the radial direction. By replacing BIR-4 RF pulses from catheter with hard-pulses, selection of a cylindrical shell is a possibility that we are currently investigating.

**Conclusion:** The first application of cylindrical encoding as a novel method for high resolution imaging is introduced.

**Preferences:** [1] E. Atalar, US patent 6031375, Feb 29, 2000. [2] Ocali et al. MRM, 37, 112-118, 1997. [3] Staewen, R. S. et. al., Invest. Radiol. 25, 559-567, 1990.