Hardware

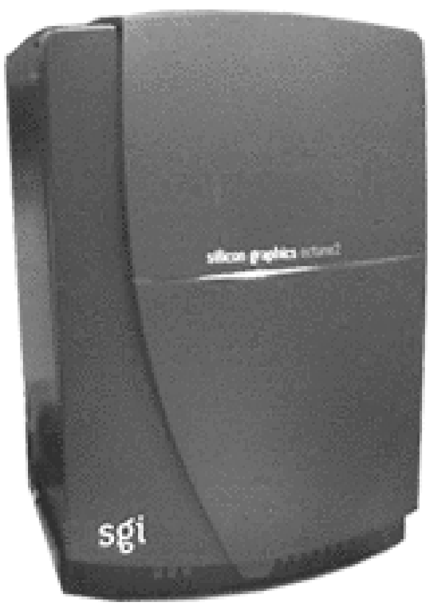
- MRI system
- Multicoil
- Microstrip

MRI System

Part1

The MRI system is made up of a variety of subsystems.

- the Operator Workspace
- Gradient Driver subsystem
- The Physiological Acquisition Controller
- Magnet subsystem



- Workstation
- + Camera and printer

The gradient subsystem

- The gradient subsystem produces calibrated magnetic fields based on digital input received from the IPG (Integrated Pulse Generator).

The Physiological Acquisition Controller (PAC)

- Acquires, digitizes, and transmits physiological signals from the patient to the IPG board. The system uses these signals to synchronize the scanner to physiological events such as patient respiration, heart beat, and pulse.

Respiratory Compensation

- is used during torso scans to help eliminate artifacts caused by patient breathing motion. The compensation is based on the patient's respiratory rate, which is measured by a bellows placed across the patient's chest or abdomen.

Cardiac gating

- is used when the specific position of the heart is important for imaging. The gating is based on the patient's heart motion, which is monitored by electrocardiogram (ECG) leads placed on the patient's chest.

Peripheral gating

- is used to minimize the effect of blood flow through the body. A plethysmograph (photopulse sensor) is placed on the patient's finger to detect blood flow.

Main Coil and Cryostat

- The main coils are mounted in a liquid helium vessel, and are submersed in liquid helium. The helium vessel is surrounded by radiation shields and is suspended within a vacuum chamber. The overall assembly is called the *cryostat*

Superconducting

- Superconducting wire has a resistance approximately equal to zero when it is cooled to a temperature close to absolute zero (-273.15o C or 0 K) by emersing it in liquid helium.
- Once current is caused to flow in the coil it will continue to flow as long as the coil is kept at liquid helium temperatures. (Some losses do occur over time due to infinitely small resistance of the coil. These losses are on the order of a ppm of the main magnetic field per year.)

Cooling System(Three Steps)

- **Coolants:**

- Helium
- water
- Air

Shim Coils

- Shim coils provide auxiliary magnet fields to compensate for in-homogeneities in the main magnetic field.

- Superconducting shim coil
- Resistive shim coil

Magnet Monitor

- Liquid Helium Meter
- Helium vessel pressure
- Helium vessel Heater (WHY?)

Magnet Rundown Unit

- The Magnet Rundown Unit quickly removes the magnetic field in a few minutes. During a rundown, over 75% of the liquid helium within the helium vessel is converted to gas, and is exhausted through the customer provided vent system.

Surface coil and multicoil

Part2

The use of surface coils increases the signal-to-noise ratio (SNR) of images.

- the coil is closer to signal-emitting protons and, therefore, receives a strong signal;
- the coil hears only noise originating near the coil, which is less than the noise that is picked up from the entire body by the body coil.

Two drawback

- One is that the usable FOV of the image is limited to the field of sensitivity of the coil
- Imaging depth

Multi-coil

- The initial release of the Phased Array option consists of a group of coils and receivers whose individual images are combined to create one image with improved SNR and increased FOV capability.

Multi-coil Design

- The coils are configured in either a longitudinal fashion, to stretch the length of the useable FOV of the coil, or in a volumetric fashion, to improve the uniformity of signal across a volume.

Question?

- Why we need preamplifier protection?

Microstrip

Part3

Microstrip RF Surface Coil Design for Extremely High-Field MRI and Spectroscopy

Xiaoliang Zhang, Kamil Ugurbil, and Wei Chen*

Why we try to design a new coil

- RF coils are a critically important factor for a high-field MRI scanner for realizing such high sensitivity. With the advent of very high magnetic field MR scanners, ranging from 3–8T for human applications, a need for efficient high-frequency RF coils has emerged.
- It is well known that radiation losses and the interaction between coil and subject increase with the increase of resonance frequency.

- **The coil is characterized by a high Q factor, no RF shielding, small physical coil size, lower cost, and easy fabrication.**

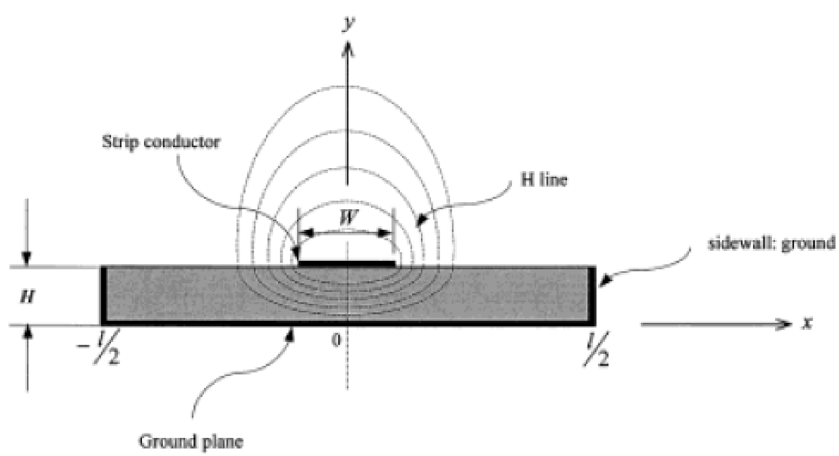


FIG. 1. A sketch of microstrip transmission line. To simplify the calculation, two ground sidewalls were added on each side. Its field distribution implies potential applications to high field magnetic resonance studies. *W* is the width of the strip conductor, *H* is the thickness of the dielectric material or substrate and *l* is the width of the ground plane.

THEORY

- In order to simplify the problem, it is necessary to place conductive sidewalls (ground) on each side, as shown in Fig. 1. Notice that most of the field lines are around the strip conductor on the microstrip line. In this case, width *l* >> thickness *H*, which ensures that both the field (electric and magnetic) lines near the strip conductor are not perturbed by the sidewalls. Therefore, the boundary conditions under this assumption should be:

Quasistatic Solution

$$\Phi(x,\ y) = 0,\ \text{at}\ x = \pm\frac{l}{2}\ \text{and/or}\ y = 0, \infty \qquad [1]$$

where $\Phi(x,y)$ is a scalar potential and satisfies Laplace's equation:

$$\nabla^2\Phi(x,\ y) = 0,\ \text{for}\ |x| \leq \frac{l}{2}\ \text{and}\ 0 \leq y < \infty. \qquad [2]$$

$$\Phi(x,\ y) = \sum_{k=1,\mathrm{odd}}^{\infty} A_k \cos\frac{k\pi x}{l}\sinh\frac{k\pi y}{l},\ \text{for } 0 \le y \le H \qquad [3]$$

and:

$$\Phi(x,\ y) = \sum_{k=1,\mathrm{odd}}^{\infty} B_k \cos\frac{k\pi x}{l}\exp\left(\frac{-k\pi y}{l}\right),$$

$$\text{for } H \le y < \infty \qquad [4]$$

$$B_k = A_k \sinh\left(\frac{k\pi H}{l}\right)\exp\left(\frac{k\pi H}{l}\right) \quad \text{for } y = H. \qquad [5]$$

$$\Phi(x,\ y) = \sum_{k=1,\mathrm{odd}}^{\infty} A_k \cos\left(\frac{k\pi x}{l}\right)\sinh\left(\frac{k\pi H}{l}\right)\exp\left(\frac{k\pi H - k\pi y}{l}\right)$$

$$\text{for } H \le y < \infty. \qquad [6]$$

Considering E field in y direction, $E_y = -\partial\Phi(x,y)/\partial y$, and then evaluating the surface charge density (ρ) on the strip at $y = H^+, H^-$:

$$\rho = \varepsilon_0 E_y\big|_{y=H^+} - \varepsilon_0\varepsilon_r E_y\big|_{y=H^-} \qquad [7]$$

- where e0, er are the permittivity or the relative dielectric constants of free space (approximately air) and dielectric material used, respectively. In the microstrip line case, obviously the charge density on the strip is 1, while outside the strip the charge density is zero if we approximate that the charge density is uniformly distributed.

$$A_k = \frac{4l\,\sin(k\pi W/2l)}{\varepsilon_0 k^2\pi^2\{\varepsilon_r \cdot \cosh(k\pi H/l) + \sinh(k\pi H/l)\}}. \qquad [8]$$

- From the above solution, some basic parameters of the microstrip resonator, such as characteristic impedance, propagation constant, wavelength, physical length, and other parameters of the coil for a certain resonant frequency can be derived.

Microstrip Transmission Line Resonator

- Another a assumption:
- For microstrip coils described in this article, the relationship between the strip conductor thickness *t* and the dielectric material thickness *H*, $t/H < 0.005$ holds. Therefore, the strip thickness *t* of the microstrip coil can be considered as zero or small enough to be negligible in practical situations

The relative dielectric constant of the substrate er, the dielectric substrate thickness *H*, and the width of the strip conductor *W* determine the characteristic impedance of the microstrip resonator. The relations for characteristic impedance are given by:

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{\mathrm{eff}}}} \ln\left(\frac{8H}{W} + \frac{W}{4H}\right)\Bigg|_{W/H \leq 1}, \qquad [11]$$

where:

$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12H}{W}}} + 0.02(\varepsilon_r - 1)\left(1 - \frac{W}{H}\right)^2 \qquad [12]$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{\mathrm{eff}}}\left\{\frac{W}{H} + 1.393 + 0.667\ \ln\left(\frac{W}{H} + 1.444\right)\right\}}\Bigg|_{W/H \geq 1}, \qquad [13]$$

where:

$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12H}{W}}}. \qquad [14]$$

The primary resonance is usually desirable for NMR experiments and it occurs when the physical length *L* (the perimeter of the coil loop) of the resonator is about half the wavelength of the primary resonance. Therefore, the fundamental resonant frequency is calculated as:

$$f = \frac{c}{2L\sqrt{\varepsilon_{\mathrm{eff}}}} \qquad [16]$$

where c is the speed of light in free space.

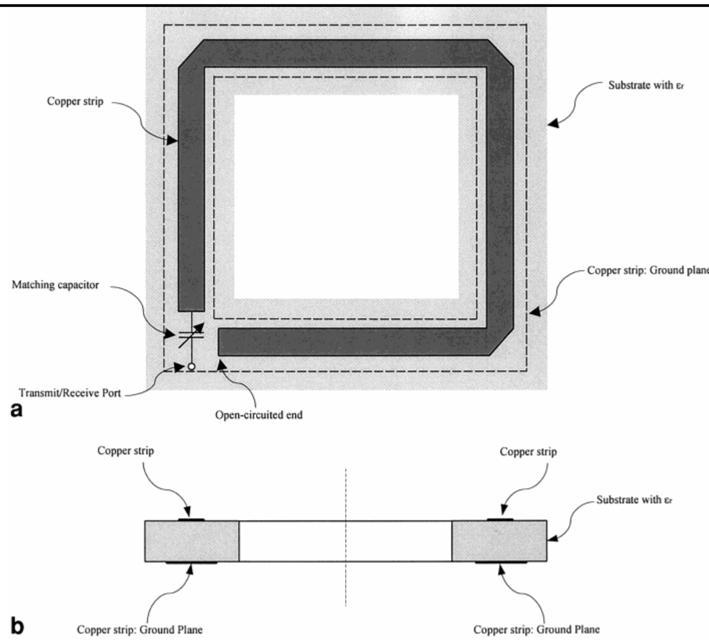


FIG. 2. Single-turn microstrip surface coil with the square shape.

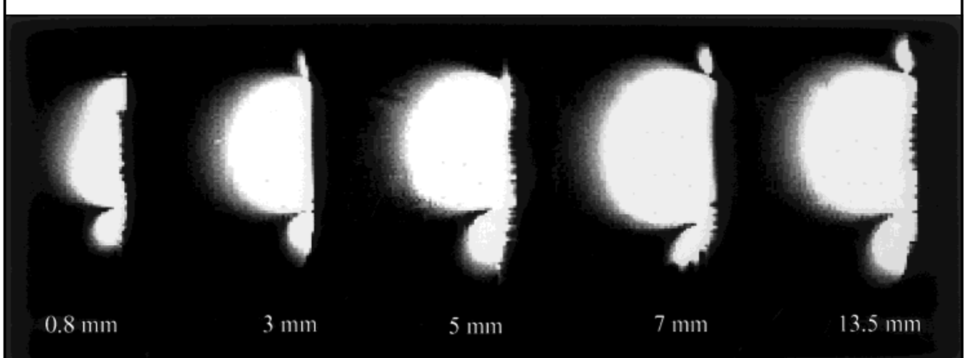


FIG. 3. A set of mineral oil GE images acquired from various dielectric material thickness (*H*) shows that *B*1 penetration increases when *H*
increases. There is no significant increase of *B*1 penetration when *H* is greater than 5 mm.

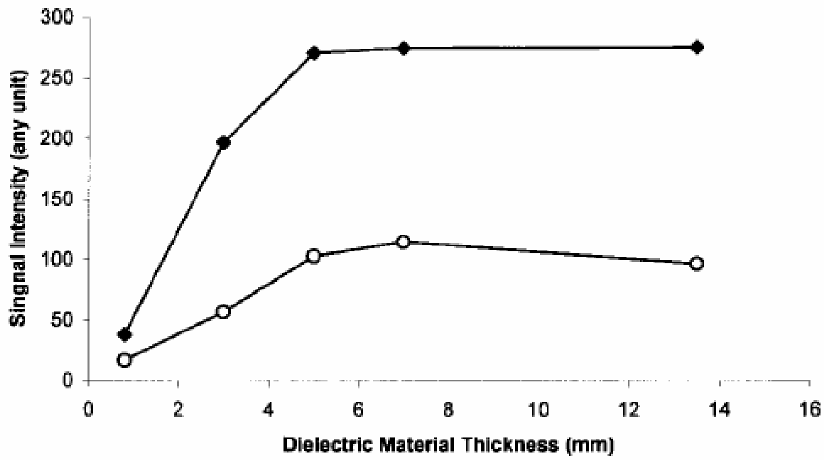


FIG. 4. Plots of signal intensities located at y = 2 cm x = z = 0 (—◆—) and y = 5 cm x = z = 0 (—○—) for different dielectric material thickness, where y is distance from the coil (H = 5 mm; coil size: 9 × 9 cm^2) along the coil axis. Assume the point of x = y = z = 0 is the center of the coils.

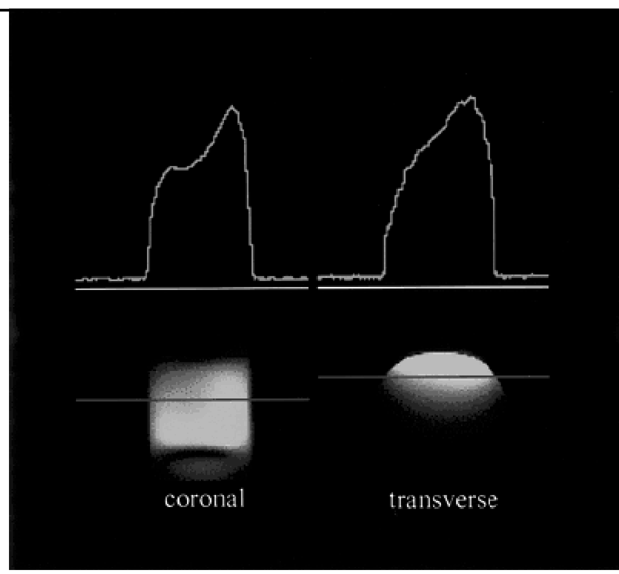


FIG. 5. Coronal and transverse GE images and 1D profiles acquired by a single-turn microstrip surface coil showing an asymmetric image intensity (or B1 field) distribution.

RESULTS

- The measured resonate frequencies were compared with the calculated results based on the method as described in the Theory section. The agreement was within 3%.
- The Q values of the single-turn squareshaped microstrip coil were 306 for unloaded case and 90 for loaded case with the human head.

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