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ELECTRONICS AND RADIO ENGINEERING

An NMR Probe Coil

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Abstract—An NMR probe coil that produces a high-frequency magnetic field as uniform as the field provided by the well-known birdcage resonator, is described. Unlike the resonator, however, the coil can easily be tuned by varying a single variable capacitor.

A resonance coil or resonator, inside which the sample to be investigated is placed, is one of the basic components of NMR devices (spectrometers and tomographs). In the state-of-the-art NMR devices based on superconducting magnet–solenoids, the internal operating volume and (logically) the resonator are shaped as cylinders, the cylinder axis coinciding with the direction of constant magnetic field $\mathbf{B}_0$. The resonator is used to produce uniform alternating magnetic field $\mathbf{B}_1$, which is normal to $\mathbf{B}_0$. As is well known, a uniform magnetic field perpendicular to the cylinder axis can be induced by a current passing along the cylinder surface, if the current amplitude is $I_0 \sim \sin\theta$, where θ is the angle measured from the direction of field $\mathbf{B}_1$ (see, e.g., [1]).

The best-known structure for utilizing this principle is the birdcage resonator [2]. It consists of N (usually, $N = 8$ or 16) parallel conductors A, uniformly distributed over the cylindrical surface, the ends of which are connected with annular conductors B. Depending on the version (lowpass, highpass, or hybrid, a combination of the first two), the resonator contains N, $2N$, or $3N$ fixed capacitors, placed between the halves of conductors A and/or B (Fig. 1). Fine tuning is performed by adjusting a variable capacitor either connected in parallel with one of the fixed capacitors or used in place of it. A drawback of this structure is that the resonator frequency and the uniformity of the magnetic field it produces depend on the capacitance of a large number of capacitors. This requires that the capacitances of the capacitors be carefully preselected, since a large spread in capacitance values deteriorates the uniformity of the field. In addition, the field uniformity is impaired when the capacitance of the capacitor used to tune the resonator to the resonant frequency is varied. This limits the tuning range and requires that the capacitance of the fixed capacitors be changed when the type of sample under investigation is changed. Various methods for the simultaneous (mechanical) trimming of all the capacitors in conductors A or B have been proposed, but these methods entail considerable complication of the resonator design.

Another well-known structure is the saddle coil, which can be easily retuned over a wide range of frequencies by adjusting a single variable capacitor [3]. The uniformity of the field produced by this coil is not high, however, due to the small number of active conductors A ($N = 4$).

Figure 2 shows a new design for a probe coil with $N = 6$, tuned by adjusting a single variable capacitor. The required current distribution is achieved by branch-

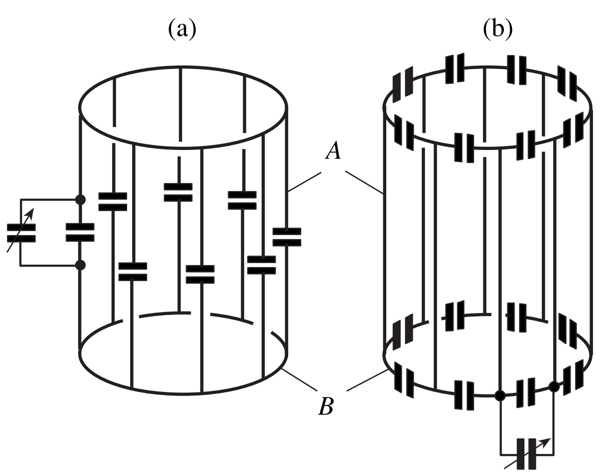

Fig. 1. (a) Lowpass and (b) highpass modifications of the birdcage resonator.

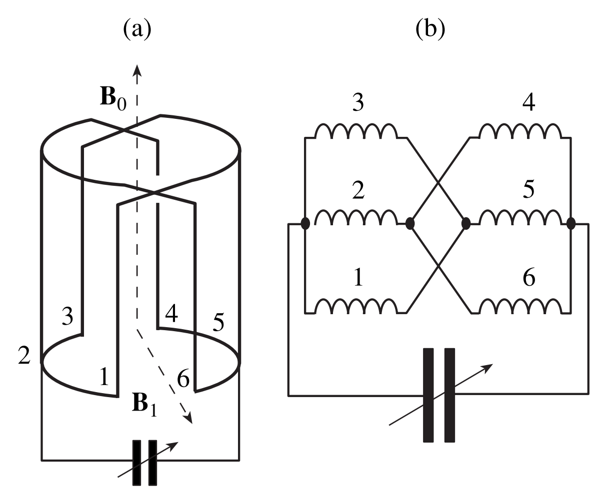

Fig. 2. (a) 3D presentation and (b) circuit diagram of an NMR probe coil.

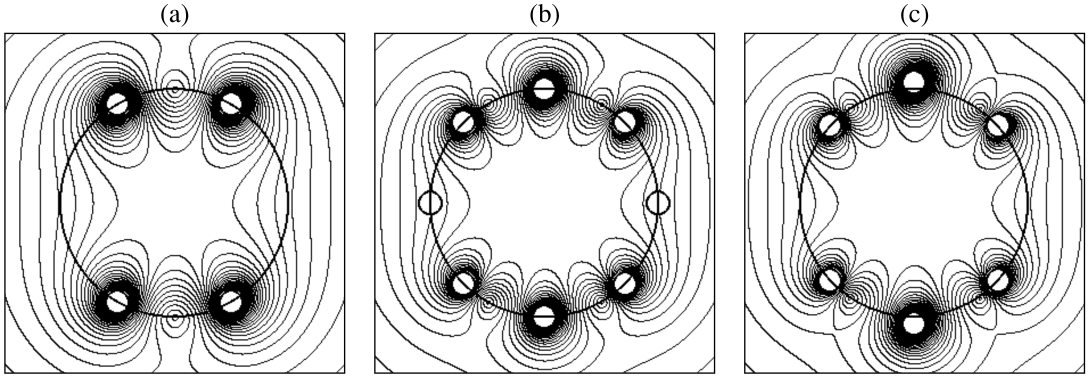

Fig. 3. Contour diagrams of the magnetic field in the coil midsection: (a) saddle coil; (b) birdcage resonator; and (c) our coil. The lines are drawn with a step of 0.05; the field at the center is assumed to be 1.

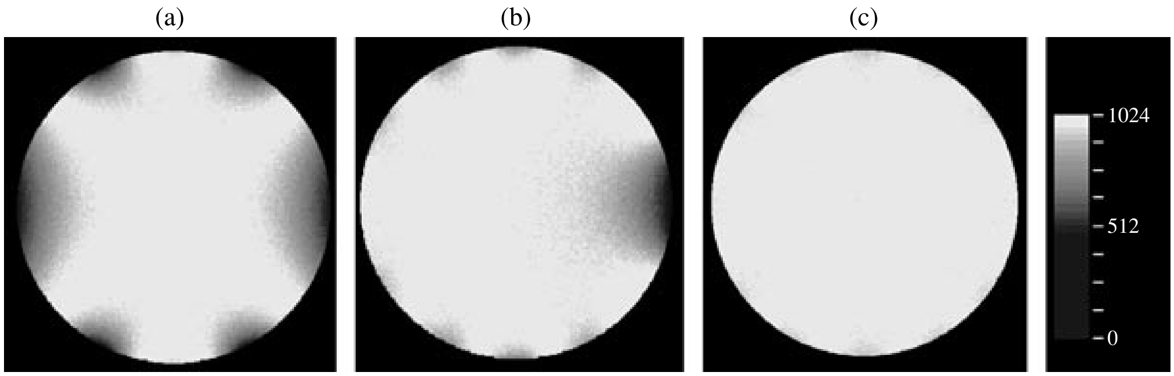

Fig. 4. NMR tomograms of a cylindrical sample of water (layer thickness, 5 mm), obtained by using (a) saddle coil; (b) birdcage resonator; and (c) our coil. A signal-level gradation scale (in conventional units) is shown at the right of the figure.

ing the circuit. In this case, the current in the first, third, fourth, and sixth conductors *A* (counting from the direction of field $\mathbf{B}_1$) is only half the current in the second and fifth conductors. An increase in the number of active conductors allows considerable improvement in the uniformity of the field produced by the coil, provided that the location of the conductors is optimal.

For purposes of comparison, Fig. 3 shows contour diagrams of magnetic fields $\mathbf{B}_1$ produced by different coils: a saddle coil, a birdcage resonator with $N = 8$, and a coil of our new design. The diagrams are constructed for the plane that is normal to the $\mathbf{B}_0$ direction and passes through the coil center. It can be seen that the field-uniformity region of the proposed coil is much larger than that of the saddle coil and is nearly the same as that of the birdcage resonator. The uniformity of field $\mathbf{B}_1$ in the $\mathbf{B}_0$ direction is also comparable for both these coils.

The main advantage of the new resonator design is its wide range of tuning, in which the uniformity of the produced field remains high. As an illustration, Fig. 4 presents NMR images (^{1}H, 200 MHz) of a cross-sectional 5-mm-thick layer in the central part of a cylindrical distilled-water sample, obtained with a saddle coil, a birdcage resonator (high-pass, $N = 8$), and our coil. The geometric dimensions of all three devices were the same (∅12.7 × 20 cm). The sample diameter was ~0.7 of the coil diameter.

The initial adjustment, including the selection of the fixed-capacitor values, was performed using a sample of half the diameter mentioned above. After the sample was replaced with a larger one, the variable capacitor's capacitance had to be reduced by a factor of two. Clearly visible in Fig. 4 is a significant deterioration in the field uniformity, due to the symmetry breakdown caused by the departure of the variable capacitor's capacitance from the nominal value of the fixed capacitors. No such disturbance is observed for the new coil design.

The proposed design for an NMR probe coil can be employed over the entire frequency band now in use (from tens of megahertz to several hundred megahertz).

REFERENCES

1. Sarkisyan, L.A., *Analiticheskie metody rascheta statsionarnykh magnitnykh polei: Spravochnoe posobie* (Analytical Calculations of Stationary Magnetic Fields: Handbook), Moscow: Energoatomizdat, 1993.
2. Hayes, C.E., Edelstein, W.A., Schenck, J.F., *et al.*, *J. Magn. Reson.*, 1985, vol. 63, p. 622.
3. Hoult, D.I. and Richards, R.E., *J. Magn. Reson.*, 1976, vol. 24, p. 71.