What is an RF coil?

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When is an RF coil not a coil? Answer: When it is used with an MRI clinical scanner. The term “RF coil” is a carry-over from the early days of nuclear magnetic resonance when the samples being studied were often in small test tubes and the frequencies were relatively low. One made a RF coil by wrapping a number of turns of wire around the test tube and connecting it to a tuning capacitor. The coil serves two functions. During the transmit mode, large currents in the coil generate a RF magnetic field B_1 that tip the nuclear spins away from their equilibrium position parallel to the main magnetic field B_0. Because the coil is tuned as a resonant circuit, much larger currents flow in the coil than are supplied by the power amplifier. During the receive mode, the precessing nuclear spins behave like small rotating magnets that induce a voltage signal in the coil. The large size of samples observed in present day MRI scanners makes it impossible to use coils made of multiple turns of wire. What we still call RF coils in MRI must provide the same two functions for the MRI scanner but have decidedly different configurations.

The RF coil is the conduit for all information passing between the patient and electronics of the scanner. As such, it is a key determinant of image quality. Because the required coil characteristics of the transmit mode and the receive mode are quite different, separate coils are often used to optimize each function. A transmit coil should provide a uniform B_1 field over the whole volume of interest so that all spins are excited in the same way. To get the required uniformity, the coil must surround the sample. Such coils are called volume coils. The prime example of a volume coil is the body coil that is installed in most clinical scanners. For the cylindrical bore superconducting magnet, the body coil is often some form of a birdcage coil or resonator. The birdcage consists of many parallel conductors stretching between two circular endrings. The term “resonator” is more appropriate because, instead of a single external capacitor used to tune a conventional coil, the birdcage incorporates multiple distributed capacitors distributed on its conductors. A resonator alternately stores its energy in the magnetic field B1 applied to the sample or in the electric field inside the capacitors. The multiple capacitors of the birdcage distribute the current among the multiple conductors unequally to generate a uniform field.

The primary function of a receive coil is to pick up the signal from the precessing nuclei and to convey it to the scanner with the least possible noise. The noise may be produced by the coil itself, by the random, thermally activated currents that occur in the tissue, and by the preamplifier that supplies the signal to the scanner. Although volume coils can also be used to receive the signal from the excited nuclei, more often the receive function is carried out by one or more surface coils. A surface coil consists of a single loop of conductor with distributed capacitors that tune the coil and match its impedance to the preamplifier. The tuning and matching is needed to insure that the preamplifier will add a minimal amount of noise to the signal. Because much of the noise comes from the tissue, the large volume of tissue in a volume coil means its signal-to-noise ratio (SNR) suffers in comparison to a surface coil. The surface coil couples strongly to the signal from a local region and does not pick up noise from more distance regions. The chief disadvantage of a surface coil is its limited field-of-view (FOV). An array of surface coil elements can retain the high SNR and expand the FOV. Combining the signals from the individual coil elements can involve using both magnitude and phase information for each coil in order to maximize the resulting SNR. Because the preamplifier's input impedance can be conditioned to minimize the cross coupling between coil elements in an array, most RF coil arrays include the preamplifiers.

When designing an RF coil, the FOV and SNR are prime considerations. However, the resulting image quality is also strongly dependent on the patient and the MRI technologist. Therefore, an equal effort must be directed toward insuring that the patient is comfortably positioned and the coil is easy to use.