The current trend in magnet design is low field open design versus high field bore design. Obviously it would be desirable to combine the two, and only time will tell whether this can be done within reasonable manufacturing costs and technical/structural limitations.

9.4 Shimming

MRI requires a very high homogeneous static magnetic field. In order to produce high-resolution images, the magnetic field inhomogeneity produced in a high performance MRI scanner must be maintained to the order of several ppm. After manufacturing, the magnet must be adjusted in some points to produce a more uniform field by making small mechanical and/or electrical adjustments to the overall field. This process is known as **shimming**. Because the magnet itself is not adequately homogeneous, it is necessary to improve or "shim" the homogeneity of the static magnetic field (B_o). A **shim** is a device used to adjust the homogeneity of a magnetic field.

Shimming (or adjustment of the static magnetic field homogeneity) is accomplished by two methods: (1) Passive shimming (2) Active shimming

Passive shimming: The mechanical adjustments, which add small pieces of iron or magnetized materials, are typically called passive shimming. Passive shimming involves pieces of steel with good magnetic qualities. The steel pieces are placed near the permanent or superconducting magnet. They become magnetized and produce their own magnetic field.

Active shimming: The electrical adjustments, which use extra exciting currents, are known as active shimming. Active shimming is performed with coils with adjustable current. Active shimming requires passage of electric current through coils with unique geometric configurations. The shim coils are designed to correct inhomogeneities of specific geometries.

In both cases (active and passive shimming), the additional magnetic fields (produced by coils or steel) add to the overall magnetic field of the superconducting magnet in such a way to increase the homogeneity of the total field.

9.5 Radio Frequency Coils

Radio Frequency (RF) coils are needed to receive and/or transmit the RF signals used in MRI scanners. RF coils system comprises the set of components for transmitting and receiving the radiofrequency waves involved in exciting the nuclei, selecting slices, applying gradients and in signal acquisition. RF coils are vital component in the performance of the radiofrequency system. They one of the most important components that affects image quality and obtaining clear images of the human body. RF coils for MRI can be categorized into two different categories: volume coils and surface coils.

9.5.1 Volume RF Coils

The design of a volume coil is to provide a homogeneous RF field inside the coil which is highly desirable for transmit, but is less ideal when the region of interest is small. The large field of view of volume coils means that by receiving the noise that they receive from the whole body, not just the region of interest. Volume coils need to have the area of examination inside the coil. They can be used for transmit and receive, although sometimes they are used for receive only. Most clinical applications volume coil is built to perform whole-body imaging, and smaller volume coils have been constructed for the head and other extremities. These coils are requiring a great deal of RF power because of their size, so they are often driven in quadrature in order to reduce by two the RF power requirements. Figure 9.5 shows two volume coils. The head coil is a transmit/receive coil; the knee coil is receive only.

Figure 9.5: shows two volume coils (a) Head coil (b) Knee coil

9.5.2 Surface Coils

Surface coils have very high RF sensitivity over a small area of interest. As the name already implies, surface coils are placed over or around the surface of the anatomy of interest to the patient directly such as the temporo-mandibular joint, the orbits or the shoulder. The coil consists of single or multi-turn loops of copper wire. They have a high **Signal to Noise Ratio** (SNR) and allow for very high-resolution imaging because their small field of view and hence they only detect noise from the region of interest. The disadvantage is that they loose signal uniformity very quickly when you move away from the coil. In case of a circular surface coil, the depth penetration is about half its diameter. Surface coils make poor transmit coils because they have poor RF homogeneity, even over their region of interest. Figure 9.6 shows a few examples of surface coils.

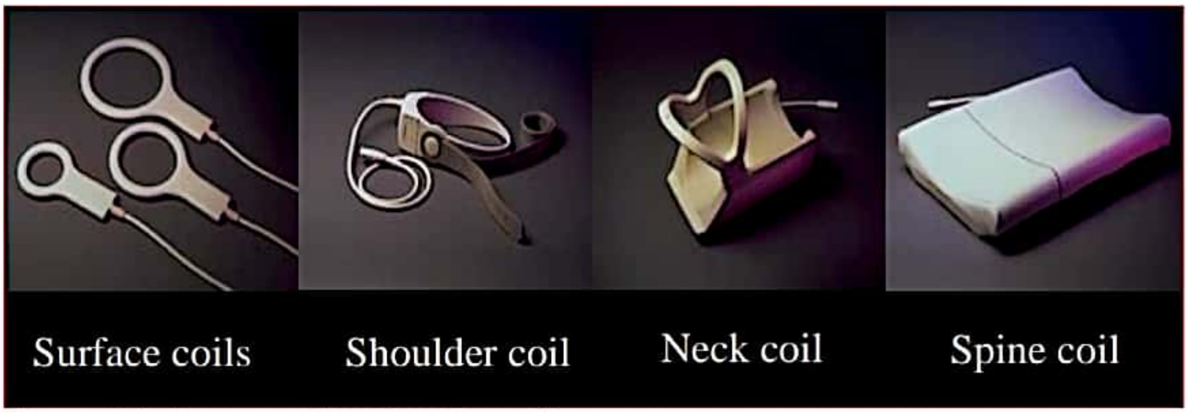


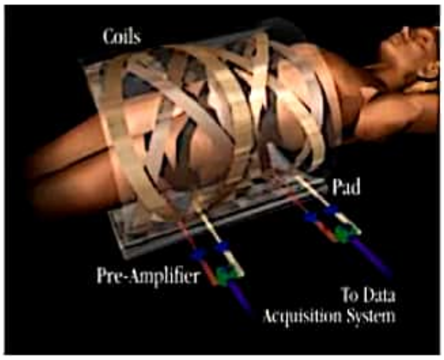
Figure 9.6: few examples of surface coils.

9.5.3 Quadrature Coils

The quadrature coil consists of two coils, which are placed at right angles to one another that mean oriented 90 degrees relative to each other. Therefore, the MRI signals received by each, coil is 90 degrees out of phase with each other. The advantage of this design is that they produce √2 more signal than single loop coils. The quadrature coil operates in the circular polarization circularization mode. The quadrature coil can generate three types of images: Real image, Imaginary image, and Magnitude image. Nowadays, most volume coils are Quadrature coils. The coils shown in Figure 9.7 are Quadrature coils.

9.5.4 Phased Array Coils

Phased array coils consist of multiple surface coils with small diameter which are combined (coil elements in phased array) to record the signal simultaneously and independently, so a greater level can be explored. Surface coils have the highest signal-to-noise ratio (SNR) than that delivered by one large diameter but have a limited sensitive area. By combining 4 or 6 surface coils it is possible to create a coil with a large sensitive area.



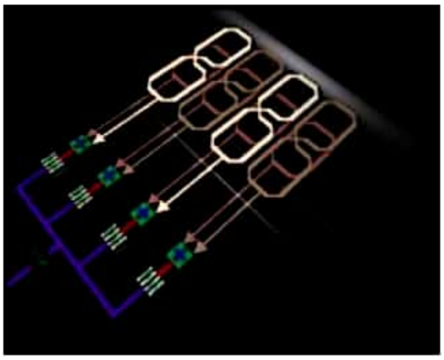


Figure 9.7: QD Body Array coil Spine Array coil

Figure 9.7 shows the design of two phased array coils. The QD Body Array coil is a volume coil, while the Spine Array coil is a surface coil. Phased Array coils produce in average √2 more signal than Quadrature coils. Today most MRI systems come with Quadrature and phased array coils.

9.6 Other Hardware

There is more hardware needed to make an MRI system work. A very important part is the Radio Frequency (RF) chain, which produces the RF signal transmitted into the patient, and receives the RF signal from the patient (see figure 9.8). Actually, the receive coil is a part of the RF chain.

9.6.1 Faraday shield

The frequency range used in MRI is the same as used for radio transmissions. That's why MRI scanners are placed in a **Faraday** cage to prevent radio waves to enter the scanner room, which may cause artifacts on the MRI image. Someone once said: "MRI is like watching television with a radio". To function properly, an MRI scanner needs to sit in a specialized room or chamber shielded against Radio Frequency (RF) interference. Without such protection the very weak RF signals that emanate from the patient when scanned would be overwhelmed. Also, to stop the radio frequencies produced by the scanner from interfering with equipment outside the cage.

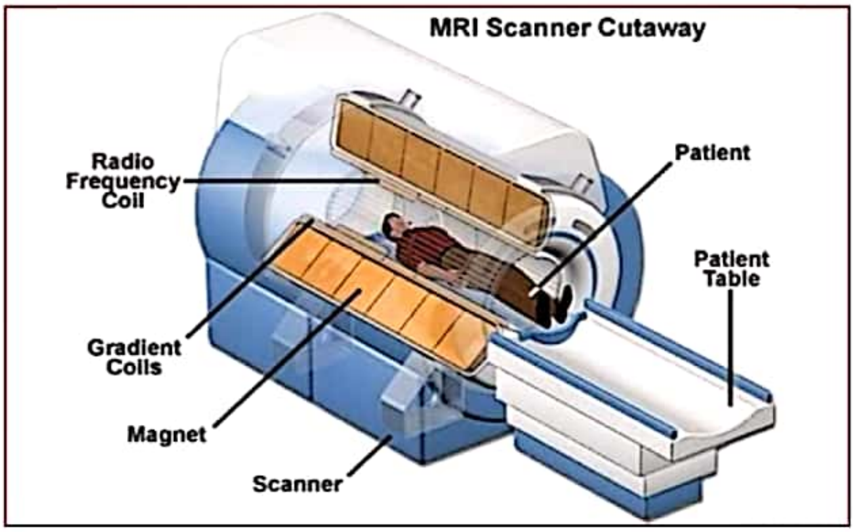


Figure 9.8: MRI Scanner Cutaway

Furthermore, one needs a processor to process the received signal, as well as to control the complex business of scanning.

9.7 Atomic Structure

All things are made of atoms, including the human body. Atoms are very small. Half a million lined up together are narrower than a human hair. Atoms are organized in molecules, which are two or more atoms arranged together. The most abundant atom in the body is hydrogen. This is most commonly found in molecules of water (where two hydrogen atoms are arranged with one oxygen atom, H_2O) and fat (where hydrogen atoms are arranged with carbon and oxygen atoms; the number of each depends on the type of fat).

The atom consists of a central nucleus and orbiting electrons. The nucleus is very small, one millionth of a billionth of the total volume of an atom, but it contains the entire atom's mass. This mass comes mainly from particles called nucleons, which are subdivided into protons and neutrons. Atoms are characterized in two ways. The atomic number is the sum of the protons in the nucleus. This number gives an atom its chemical identity. The mass number is the sum of the protons and neutrons in the nucleus. The number of neutrons and protons in a nucleus are usually balanced so that the mass number is an even number. In some atoms, however, there are slightly more or fewer neutrons than protons. Atoms of elements with the same number of protons but a different number of neutrons are called isotopes. Nuclei with an odd mass number (a different number of protons to neutrons) are important in MRI (see later).

Electrons are particles that spin around the nucleus. Traditionally this is thought of as being analogous to planets orbiting around the sun. In reality, electrons exist around the nucleus in a cloud; the outermost dimension of the cloud is the edge of the atom. The position of an