RF Prototyping Techniques

Building a single loop NMR coil is usually the beginning point for anyone interested in making their own coils. In fact, it is a very good basis on which to learn the fundamentals of coil construction, and simple enough to achieve success and encouragement to pursue more complex structures. This presentation will utilize the single loop coil to discuss impedance matching, balanced matching and baluns, distributed capacitance, Q-spoiling, field measurements with split-loop probes, phantoms, and Q measurements.

A common impedance matching method is to use a reactive component placed in series with the resonant coil. The principle behind this matching method is that the capacitor in parallel to the coil is chosen such that the complex impedance looking into the parallel combination is, \( Z_p = Z_0 \pm jX_m \) (Eq.1), where \( Z_0 \) is the characteristic impedance of the system, usually 50 \( \Omega \), and \( jX_m \) is a positive or negative reactance that results from picking the parallel component to yield the real part of \( Z_p \) equal to \( Z_0 \). The value of the series matching component can then be chosen to have the equal and opposite reactance of \( jX_m \) in Eq. 1, such that the total impedance looking into the network is, \( Z_t = 50 + jX_m - jX_m = 50 \Omega \) (Eq.2) for a capacitor as series element or \( Z_t = 50 - jX_m + jX_m = 50 \Omega \) (Eq.3) for an inductor as series component. A Smith chart applet will be demonstrated in class as a design aid.

Balanced matching circuits and baluns (balanced to unbalanced) improve coil symmetry and reduce vulnerability to unwanted voltages. The simple balanced match [1] is an extension of the single sided match described above, using two equal reactances placed on either side of the coil. Alternative balanced matching circuits include discrete component lattice-type baluns [2-4] as shown in the adjacent figure. The circuit in c has perfect anti-symmetry (equal amplitude, opposite phase) at the coil input and if implemented properly provides the best defense against unwanted voltages.

The transformation of a dipole antenna to NMR coil is interestingly described by Chen and Hoult [2] and demonstrates the transition from an efficient far-field antenna to near-field tuned circuit having field homogeneity sufficient for NMR. The addition of multiple capacitors (distributed capacitance) around the coil leads to decreased electric field losses and increased frequency of operation. It is common practice to limit the length of any coil segment to be less than \( \lambda/20 \) to \( \lambda/10 \). A cautionary note: large numbers of distributed capacitors may cause excessive losses in the additive series resistance of the capacitors. The builder must decide when the distribution has become counter productive.

The discussion so far has assumed the coil is to be used for transmission and reception. However, the vast majority of clinical coils utilize a surrounding body coil for homogeneous transmission and smaller surface coil(s) for reception. Such a surface coil must be ‘turned off’ during the transmission cycle of the MR experiment. This can be accomplished with Q spoiling, a high impedance circuit switched into the coil loop to reduce circulating current. The switching is accomplished with an actively biased PIN diode or a passive antiparallel diode pair. The high impedance circuit can be accomplished in two ways: 1) with an inductor placed in parallel with a distributed capacitor and having a reactance magnitude equal to that of the capacitor, or 2) with an inductor as the series element in the impedance matching circuit and having a reactance magnitude equal to that of the shunt capacitor. This requires that the capacitor and inductor be carefully chosen to satisfy the impedance matching requirements of Eq.3 above.

Time permitting, other concepts to be presented in the tutorial are field measurements with split loop probes, Q measurements, and saline phantoms.