RF-Invisible Inductors

V. Taracila[1], V. Alagappan[1], A. Zemskov[1], and F. Robb[1]
[1]GE Healthcare, Aurora, Ohio, United States

Introduction

In MR Imaging the RF coupling properties of reactive components like inductors and capacitors used for building Phased Array Coils are very important. Ideally these components must have lump circuit characteristics only, without manifesting any stray radiation. These goals might appear to be contradictory since inductors and capacitors with higher inductances and capacitances respectively must have bigger volumes and a certain surrounding volume for magnetic and respectively electric fields confinement [1]. In this work we address the question of the "invisible" inductors – inductors with highly confined magnetic field, which still have satisfactory inductive characteristics. A classical inductor (Figure1a) is usually a loop with one or multiple turns. The magnetic field exhibited by such an inductor is primarily a magnetic dipole type. Inductors used in MRI cannot contain magnetic cores, because of very tight B0 distortion requirements. With an air core approach on the other hand, it is difficult to obtain a high inductance at the same time having a very confined magnetic field.

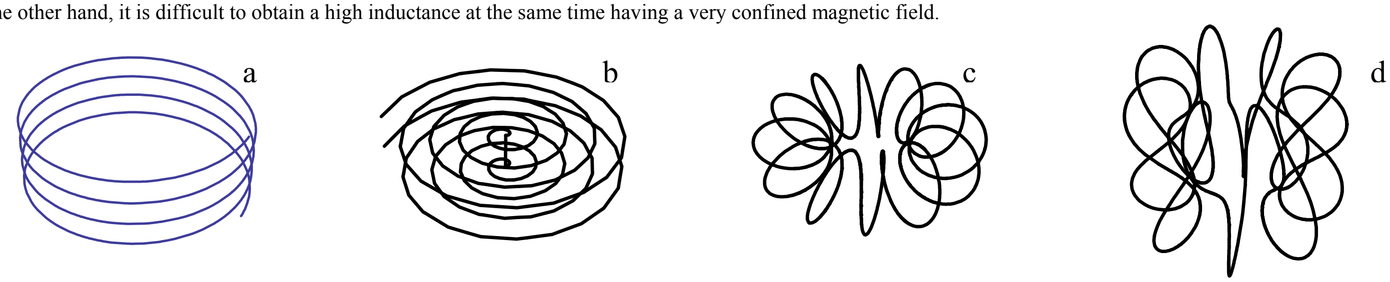

Figure 1. Inductors built from 15 cm wire with overall maximal dimensions smaller then 1cm^3: a) Multi-turn cylindrical inductor; b) double spiral; c) torus; d) lemniscates shaped inductor.

Theory

Let us consider the inductor dimensions (overall diameter and length of the wire), which are much smaller, then the wavelength of the radiation it exhibits in vacuum. As an inductor we have to create the highest achievable inductance however from "RF-invisibility" standpoint it must have a very confined magnetic field pattern. Receiving and transmitting characteristics of the closed contour antenna can be described through magnetic and electric multipolar expansion of the magnetic and electric field respectively [2]. It is known that when the antenna represents a closed contour with small electric length (we can consider only magnetic multipolar radiation pattern [3]. A good transmit and receive antenna must have very high electric and magnetic moments. Thus, create an "invisible" inductor we need to consider minimization of the magnetic dipole radiation in the first degree, quadrupole radiation in the second degree etc.

The magnetic dipole is defined as

$$\mathbf{m} = \frac{1}{2}\int \mathbf{r}\times\mathbf{j}\,dv \qquad (1)$$

On the other hand the inductor still has to perform as a storage for magnetic energy or having a high self-inductance.

$$L = \frac{\mu_0}{4\pi}\int \frac{\mathbf{j}(\mathbf{r})\mathbf{j}(\mathbf{r}')}{|\mathbf{r}-\mathbf{r}'|}d\mathbf{r}d\mathbf{r}' \qquad (2)$$

Be minimizing the function (1) and maximizing the function (2), we can modify the geometry of the certain inductor in accomplishing the two goals: poor emissivity (receptivity) and high self-inductance.

	Bobbin	Double Spiral	Torus	Lemniscate
Mx,[µAm]	0	0.9	0	0
My,[µAm]	15	-3.8	0	0
Mz,[µAm]	452.2	0	56.2	30.6
L,[nH]	203.4	60.3	91.2	55.0

Table1. Dipole magnetic moments and self-inductance for 150 mm thin wire shaped according to topologies from Figure 1.

Results

We perform this study by chosing several topologies with good confinement characteristics and tried to evaluate the two expressions (1,2) for every case (Table1). For a fixed length of the wire we tried to build inductors with minimal magnetic dipole moment and maximal inductance. We picked as contenders: a double spiral, torus and a lemniscates based inductors. Length constraint is important in the case of balun construction, when a certain length of a transmission line must be considered.

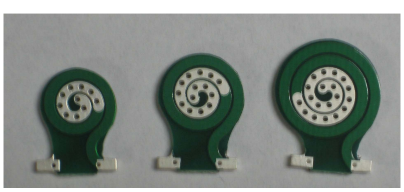

Figure 2. Tunable double spiral inductors: the holes allow connection of the two spirals though a via. For 128MHz the inductors can be made resonant with capacitors from 20 to 100 pF.

Discussions and Conclusion

In many areas of RF antenna design and circuitry, RF-invisible lump circuit component are required. Receive MR coils must be decoupled during transmit phase from the transmit coil, usually the body coil. All electronic component placed on the antenna are also in the strong field of transmit coil radiation. Many of these components are tuned to the system frequency, therefore the antenna-like pattern is very critical. This problem put serious obstacles in RF circuit packaging and has to be addressed with appropriate guiding rules. We have shown that through calculation of magnetic dipole moments and inductance for a certain topology of the inductor ant other additional constraints like length, overall diameter or volume, it is possible to address and characterize to problem of "RF-invisibility" or magnetic transparency for inductors. From our results (Table 1) we chose to implement the double spiral inductor (Figure 1b). Its flat shape permits implementing a printed circuit board (PCB) version (Figure 2). This topology with multiple holes for via connecting the two spirals, allows fine adjustment of the inductance. To increase the inductance, multiple paired layers of symmetric spirals could be quickly designed.

References

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