A Parallel Transmit Volume Coil With Independent Control of Currents on the Array Elements

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Introduction

The dielectric property of tissues shortens the wavelength of the RF magnetic field in the body. It tends to produce significant inhomogeneity in B_1 distribution at high frequency, which is inimical to diagnostic imaging. Due to the advantages of high frequency imaging in terms of SNR, spatial and temporal resolution, there is considerable interest in the development of radio frequency volume coils that are capable of generating uniform B_1 at high frequency. With the recent development of the theory of Transmit SENSE [1] and the consequent renewal of interest in multi-dimensional imaging [2], which allows selective excitation of specific regions of interest and perhaps, optimization of B_1 homogeneity [3], there is urgent need for a parallel transmit system [4]. Both applications mentioned above require the capability of individual and independent control of the amplitude and phase of the currents on each of the coil elements. The development of an 'active rung' has been described in [5] based on the principle of the antennafier element [6]. In this work, we develop further, the concept of the active rung as an element of a volume coil. We demonstrate the key concept of independent control of the rung current amplitude and phase, independent of the current in other rungs, due to suppression of induced currents in an active rung. We further demonstrate, as an application of the key concept, B_1 pattern control using an array of active rungs arranged in a transmit-only volume coil configuration.

Method

An active rung may be used as a current element by tuning the rung to series resonance at the imaging frequency such that it forms a low resistance path between the RF current source and ground. It may also be used as a conventional TEM element by tuning the rung such that it forms a resonant loop with the output parasitic capacitance of the MOSFET, C_{os}. Two experiments were performed to demonstrate the independent behavior of current elements. First, the effect of induced emf in an active rung tuned first as a current element and then as a TEM element, due to an adjacent current carrying conductor was studied. Next, the concept of independent control of rung current amplitude and phase was studied when an active rung, tuned first as a current element and then as a TEM element, was driven in the presence of the same adjacent conductor, carrying a current of amplitude 3.65A (pk-pk) and arbitrary phase. This concept was then used to demonstrate B_1 pattern control. An eight channel transmit-only phased array volume head coil consisting of eight active rungs was constructed as shown in Fig. 1. The complete RF transmit/receive coil system, consisting of the transmit-only phased array, the receive-only volume coil and the controller module, was integrated with the GE Eclipse 3T scanner. The current amplitude and phase distributions required to generate the B_1 patterns of the resonant modes of an eight rung TEM coil were calculated. The calculated current distributions were set up on the active rungs of the transmit phased array by adjusting the amplitude and phase of the corresponding input RF voltage. These adjustments were made by setting the corresponding DC control voltages of the phase shifters and attenuators in the controller module to the appropriate values. B_1 maps corresponding to the above current distributions were created by imaging a non-loading silicone oil phantom (σ=0S/m, ε=2.2) using a Gradient echo pulse sequence (α=20^o, TE=20ms, TR=800ms). The resultant B_1 maps were compared to the simulated B_1 maps of the resonant modes of an eight rung TEM coil, which occur at eigen frequencies defined by the self and mutual impedances of the coil elements.

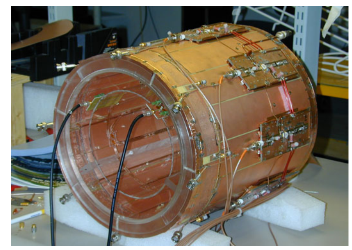

FIG. 1 Picture of the eight channel transmit-only phased array volume coil. Each channel is an active rung tuned as a current element. The quadrature saddle receive coil can also be seen.

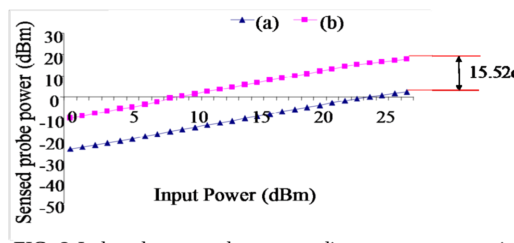

FIG. 2 Induced current due to an adjacent current carrying conductor in a current element (a) is suppressed by 15.52dB compared to that in a TEM element (b).

Results

A comparison of curves (a) and (b) in Fig. 2 shows that the induced current in a current element is suppressed by 15.52dB compared to that in a TEM element. This may be attributed to the fact that the high internal resistance of the MOSFET forces the induced current to flow in the loop formed by the rung, which is series resonant at 127.72MHz and C_{os}, the output parasitic capacitance of the MOSFET. This loop was found to be off resonance by about 7MHz. A comparison of curves (a) in Fig. 2 and (b) in Fig. 3 shows that the dynamic range of independent control of rung current in a current element is limited, at the lower end, by the induced current. A MOSFET with a smaller value of C_{os} would therefore result in greater suppression of induced current and consequently, greater dynamic range of independent control of rung current. Independent control is possible because the MOSFET forces current into the rung and the amplitude and phase of the forced current are determined solely by the input RF voltage. Thus, the characteristic B_1 maps of the resonant modes of an eight rung TEM coil are replicated at the 3T imaging frequency (Fig. 4) by directly setting up the calculated current amplitude and phase distributions on the active rungs of the transmit phased array volume coil simply by adjusting the DC control voltages of the phase shifters and attenuators in the controller module.

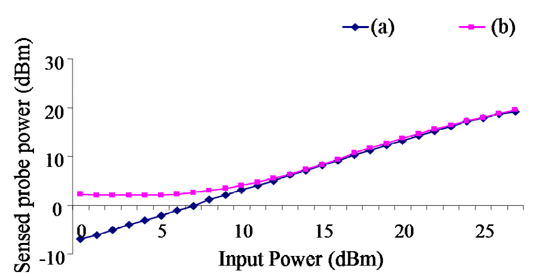

FIG. 3 The driven current in a current element in the presence of an adjacent current element (b) coincides with the ideal standalone curve (a) over a 16dB range. This is the dynamic range of independent control of rung current.

Conclusion

We have demonstrated independent control of current amplitude and phase in a current element due to suppression of induced current. This is a critical result, using which we have demonstrated that the process of setting up desired B_1 patterns in the imaging volume using an array of current elements is deterministic and not iterative. This design has the potential to vastly simplify the process of B_1 shimming at high imaging frequencies. For multidimensional imaging and transmit SENSE, this design has the potential to significantly reduce corruption of pulse profiles on coil elements by induced currents.

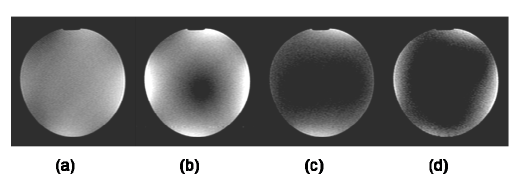

FIG. 4 B_1 maps of resonant modes (a-d) of an eight rung TEM coil obtained by setting up current amplitude distributions and imaging a silicone oil phantom at 3T.

References

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