Single-shot dual frequency excitation for magnetic induction tomography (MIT) at frequencies above 1 MHz

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Abstract

In order to make MIT fast it is recommendable to excite several transmit coils in parallel and to acquire all receive channels simultaneously. The separation between the transmit channels can be achieved e.g. by slightly separating the excitation frequencies, so that it is possible to separate their contributions in the receivers by synchronous demodulation. One major problem is the low output impedance of the driver amplifiers so that each transmit coil acts as short circuited when seen from the other transceivers and hence perturbs the primary field. This causes a number of complications both in the reconstruction software as well as from the viewpoint of SNR optimization. Therefore we propose a special passive coupling network which transforms the low driver impedance into a high termination impedance for the coils at two frequencies (1 MHz and 10 MHz). We designed a dual-frequency transformation networks which operates at 1 and 10 MHz and which provides a termination impedance $> 5 \ k\Omega$. The feeding current is typically 10mA per Volt driving voltage.

1   Introduction

Magnetic induction tomography (MIT) is an imaging modality which aims at the contact-less mapping of the complex electrical conductivity inside an object, e. g. a human body [1]. This is achieved by placing the object inside an array of transmit coils (TXC) which, by applying an AC magnetic field, cause eddy currents to flow. The resulting secondary magnetic field depends on the conductivity distribution inside of the coil array. The conductivity distribution is reconstructed from the voltages induced by the total magnetic field in an array of receiver coils (RXC). In medical MIT changes of the induced voltages by conductivity changes inside the object are by many orders of magnitude lower than the voltage induced by the primary field and hence there are many difficulties to be overcome both in hardware design as well as in image reconstruction. In principle single-shot data acquisition can be achieved

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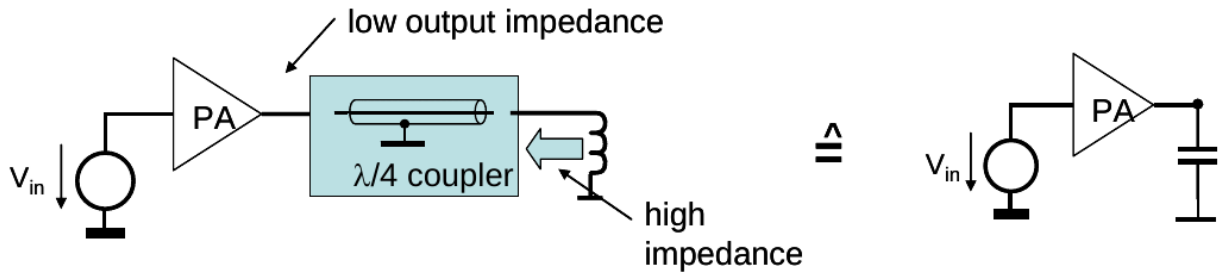
Figure 1: left: transformation of the low output impedance of the PA into a high termination impedance for the coil. right: transformation of the coil inductance into a capacitive load by the coupler.

fairly easily, e. g. by driving all TXCs at the same time. Different coils operate at slightly different frequencies, so that it is possible to separate their contributions in the receivers by synchronous demodulation. One major problem is introduced by the driving power amplifier (PA) of the TXCs: If its output impedance is low, each transmit coil acts as if it were short circuited when seen from the receivers and perturbs the primary field considerably. Thus the field perturbation has to be considered in the reconstruction algorithm, which requires the explicit modelling of the coils and sophisticates the numerical solvers. Moreover magnetic coupling between the TXCs can propagate noise generated by the power amplifiers to the RXCs to a wider extend than if the TXCs were magnetically decoupled. This problem has been tackled in [2] by driving the coils by current sources below 1 MHz. However, the performance of current sources built with amplifiers and feedback networks gets poor when approaching high frequencies due to stability problems. In this paper an alternative approach is suggested which is based on the transformation of the low output impedance of the PA into a high impedance at the TXC side.

2   Methods

Two goals must be met in order to achieve a proper operation:

- provide a high termination impedance to the TX coil

- drive the same coil at two or more different frequencies

If the spacing between the frequencies is large enough (e. g. 1 MHz − 10 MHz) goal 1 can be achieved by 2 $\frac{\lambda}{4}$ line transformers or the corresponding passive π-networks made with lumped reactive elements. Such networks transform a low impedance at one port into a high impedance at the second port at their resonance frequencies according to $Z1 = Z02/Z2$ where $Z1, Z2$ are the impedances at ports 1 and 2 and Z0 is the characteristic impedance of the coupler. Therefore using a simple push-pull amplifier with low output impedance can drive a current through the transformer
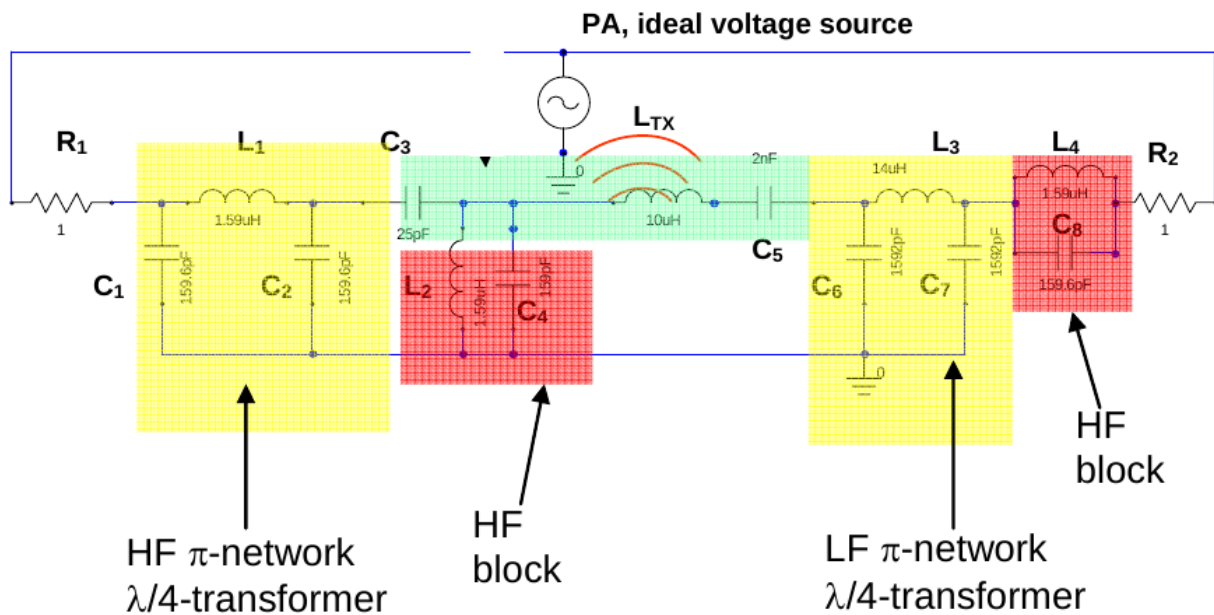
Figure 2: Complete dual frequency circuit.

while the coil 'sees' a high impedance and thus does not provide a significant field perturbation. The idea is illustrated in fig. 1 (left). The network transforms the inductance of the TXC into a load capacitance for the PA which may be unfavorable for safe operation (fig. 1, right). It is therefore advisable to drive the coil in resonance by introducing a series capacitor.

Goal 2 can be achieved by providing two driving paths for the same TXC, one for low frequency (LF) and another one for high frequency (HF). Fig. 2 shows such a network which operates at 1 MHz (LF) and 10 MHz (HF).

The LF signal travels through the LF-π-network, the LF-series resonator (formed by the TXC and C5) and L2 in the HF blocking filter L2/C4. The path through the HF feeding network is blocked by the small capacitance C3 which provides a high impedance at the low frequency. The TXC sees a high impedance, because the LF π-network shows a high impedance and the HF resonance capacitor C3 has high impedance at LF so that the HF-feeding path is cut off.

The analysis of the HF path can be done in an analogous manner. Here the TX series resonator is made up by LTX and the three capacitors C3, C5 and C6. However, as C3 is comparatively small, the resonance frequency is essentially determined by C3. C6 provides a convenient path to ground while the HF π-network establishes the connection to the PA. The TX coil again sees a high impedance, because the HF π-network shows high impedance and the network formed by L2 and C4 represents a parallel resonator at HF, thus cutting off the signal path.

Needless to say that the impedance transformers can also be made from transmission

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lines, but then the length may become impractically large and the characteristic impedance cannot be chosen arbitrarily when relying on commercially available cables (50 Ω and 75 Ω). For 10 MHz e. g. the cable length of a commercial 50 Ω line must be approx. 5 m. This is still feasible, especially if the cable simultaneously acts as the feeder line. At lower frequencies a circuit with lumped elements is certainly preferable. Transmission line couplers, however, have the nice property that they operate at all odd multiples of the quarter wavelength and hence are intrinsically suitable for certain multifrequency applications where such multiples can be used as carriers.

The network in fig. 2 was simulated assuming a driver output impedance of 1 Ω, mimicked by the resistances R1 and R2. Simulations were done with Ansoft Designer SV, ver 2.2.0 (evaluation version, Ansoft Corp.). Then the network was built up and characterized with a network analyzer (ZVL3, Rohde and Schwarz).

3   Results

Fig. 3 shows the simulated termination impedance as seen from the TXC when simulating the network presented in fig 5 assuming a driver output impedance of 1Ω. The impedance at 1 MHz is $5.5 k\Omega$ while at 10 MHz a value of $> 8\ k\Omega$ is reached. The values depend on both the driver output impedance and the characteristic impedance Z0 of the π-network. Higher Z0 yields higher termination impedance but at the same time reduces the coil current at constant driver voltage. Thus higher impedances can only be reached when simultaneously increasing the driving voltage. Fig. 4 shows real data measured with the network analyzer (center frequency 6 MHz, span 12 MHz, measurement bandwidth 100 Hz, feeding power 20dBm) when the input port was shorted. The achieved peak values are somewhat higher than in the simulation due to ideal shorting and a somewhat higher coil quality than assumed in the simulation. The current in the TX coil is given as I=V0/Z0 whereby for the realized couplers Z0 is given by $2\pi L f_0$, L being L1 an L3 and f0 being the resonance frequencies, i. e. 1 MHz and 10 MHz, respectively. V0 is the output voltage of the feeding amplifier. In our case Z0 was 100 Ω at both frequencies, so that I is 100mA when the when the PA drives 10 V.

4   Discussion

Our results show the feasibility of achieving high-impedance termination of the TX coils at two frequencies with a simple passive network. Thus, driving currents up to several hundreds of mA with low-impedance PAs is possible and the field perturbation can be kept low. However, there arise also some drawbacks of this design: (1) thermal drifts of the electrical parameters may change the resonance frequencies and hence the performance of the circuit at the nominal operating
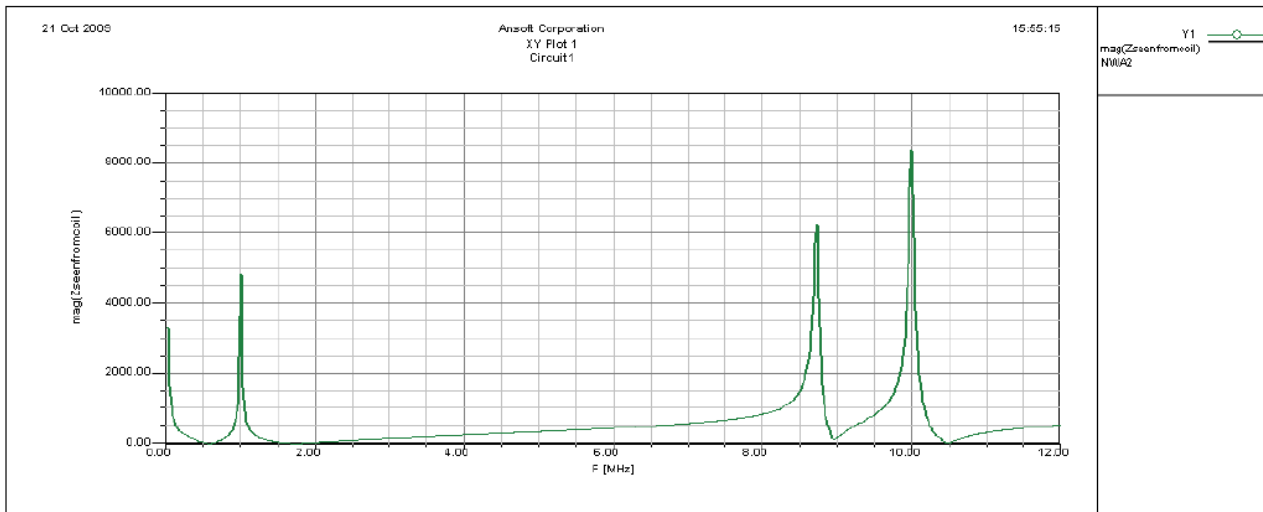
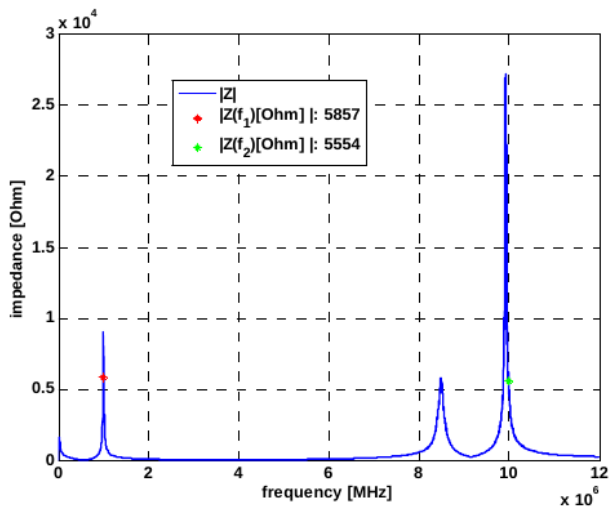Figure 3: Termination impedance (magnitude) seen by the TXC as a function of frequency.

Figure 4: Termination impedance (magnitude) measured at the real network with a netwok analyzer when the input port was shorted. The two stars mark the actual readings at exactly 1 and 10 MHz.

frequencies. (2) Unless ideally tuned the network introduces a phase shift so that there is no well-defined phase relationship between driving voltage and received signal. Thermal drifts make it necessary to frequently re-calibrate the reference phase for demodulation. In principle this goal can be achieved by using the method suggested in [3].

5   Acknowledgements

6   References

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