Feasibility of Nuclear Quadrupole Resonance as a technique for detecting person-borne explosives

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ALERT
AWARENESS AND LOCALIZATION OF EXPLOSIVES-RELATED THREATS

Abstract

Current technology for screening individuals at secure areas is most capable of identifying metallic objects and objects carried outside of the body. Surgically implanted explosive devices remain challenging to detect. This preliminary research assesses the feasibility of using nuclear quadruopole resonance (NQR) as a technique for detecting person-borne explosives, including those that are surgically implanted or ingested.

To use NQR, electromagnetic fields in the radio band (0.5-6MHz) are applied to a sample in order to determine whether an explosive is present within that sample. When such a field is applied to a human body, it is scattered and attenuated by human tissues, bones, blood, and other structures. These complex effects make it difficult to predict the ability of a given antenna configuration to sufficiently energize and subsequently detect a concealed explosive. An FDFD model can account for scattering and attenuation within a subject and determine the field at a given point within or on the body. This enhanced understanding of the field's interaction with human anatomy may be a powerful tool in developing antenna configurations capable of quickly detecting an explosive anywhere on or within a person.

Introduction to NQR

Atomic nuclei with spin number greater than ½, such as ^{14}N, posses an electric quadrupole moment. This leads to the nucleus being able to take on three distinct energy levels as it changes its orientation with respect to the electric field gradient (EFG) [1]. The energy difference between each allowable eigenstate corresponds to a specific frequency of electromagnetic radiation via Planck's relation. For a ^{14}N nucleus occupying its ground state, there are therefore two frequencies of radiation, v_- and v_+, which are capable of exciting the nucleus into its second or third energy state respectively.
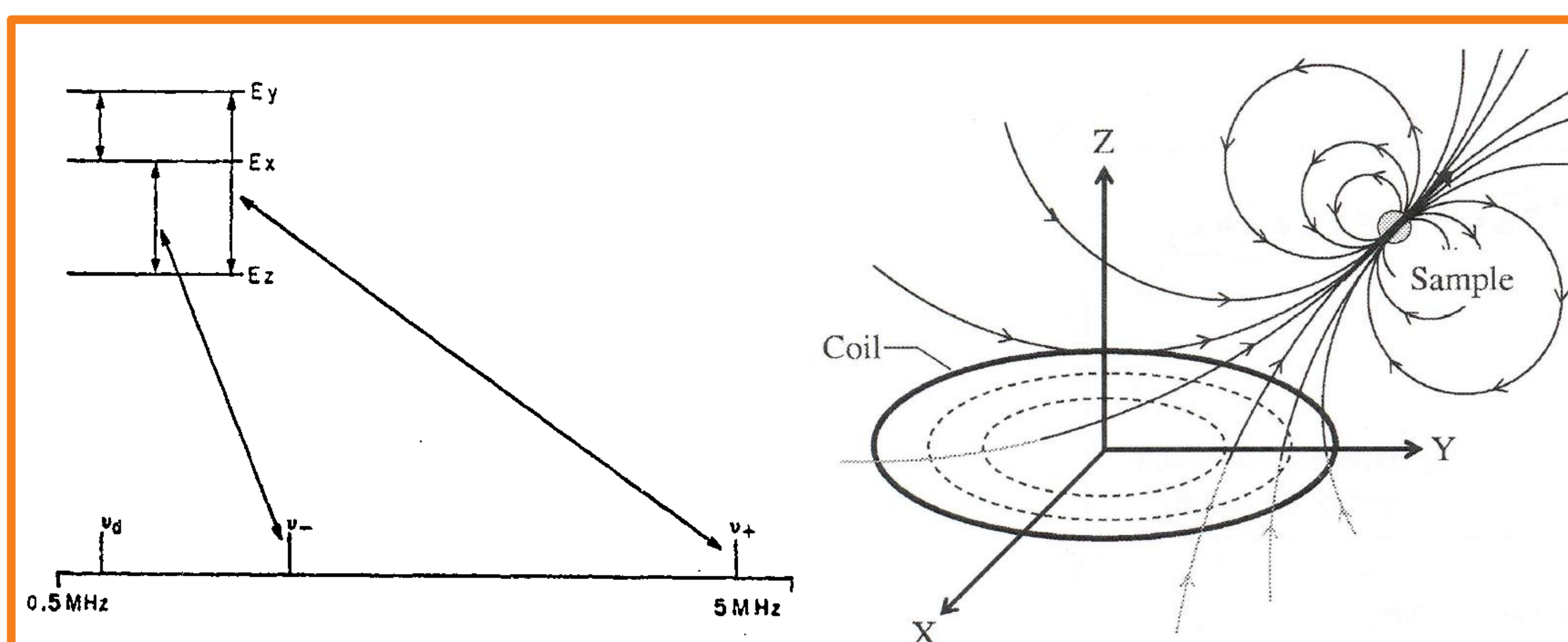

Figure 1: The three energy levels of ^{14}N and corresponding transition frequencies (left [2]). A coil antenna being used to detect the signal from the sample (right [3]).

After having been excited to a higher frequency by the appropriate field, the nucleus returns to its ground state and re-emits radiation at the same frequency which was applied to it.

The ^{14}N nucleus is extremely common in explosives. Therefore, the described resonance phenomena exists in TNT, RDX, PETN, and more. Since the eigenstates are determined by the EFG, each ^{14}N nucleus within a given kind of molecule has its own resonant frequencies. These frequencies are distributed from 0-6MHz, and each has a small bandwidth, giving each explosive containing ^{14}N, a fingerprint-like set of characteristic frequencies [4].

Initial Assessment

A review of the current literature on NQR detection is used to qualitatively asses whether NQR may be suitable for detecting person-borne explosives.

◊ **Safety –** The frequencies used in NQR for detecting explosives are below 6MHz, and overlap with the frequencies used to transmit radio signals. This radiation is non-ionizing and very low energy, so is expected to be completely safe for use with people.

◊ **Ability to detect deeply concealed bombs –** Radio band fields represent the quasi-static case and completely penetrate clothing and the body. This allows explosives concealed behind clothing or tissue to be reached by the detector.

◊ **Privacy –** NQR simply indicates the presence or absence of an explosive, but is not an imaging technology and would not be prone to the same privacy concerns as them.

◊ **Low False Positive Rate –** As a bulk-detection technology with the capacity for self-correction, an NQR scanner may have very few false-positives. Conversely, test results using NQR for land-mine detection indicate a very high rate of detection in a field setting.
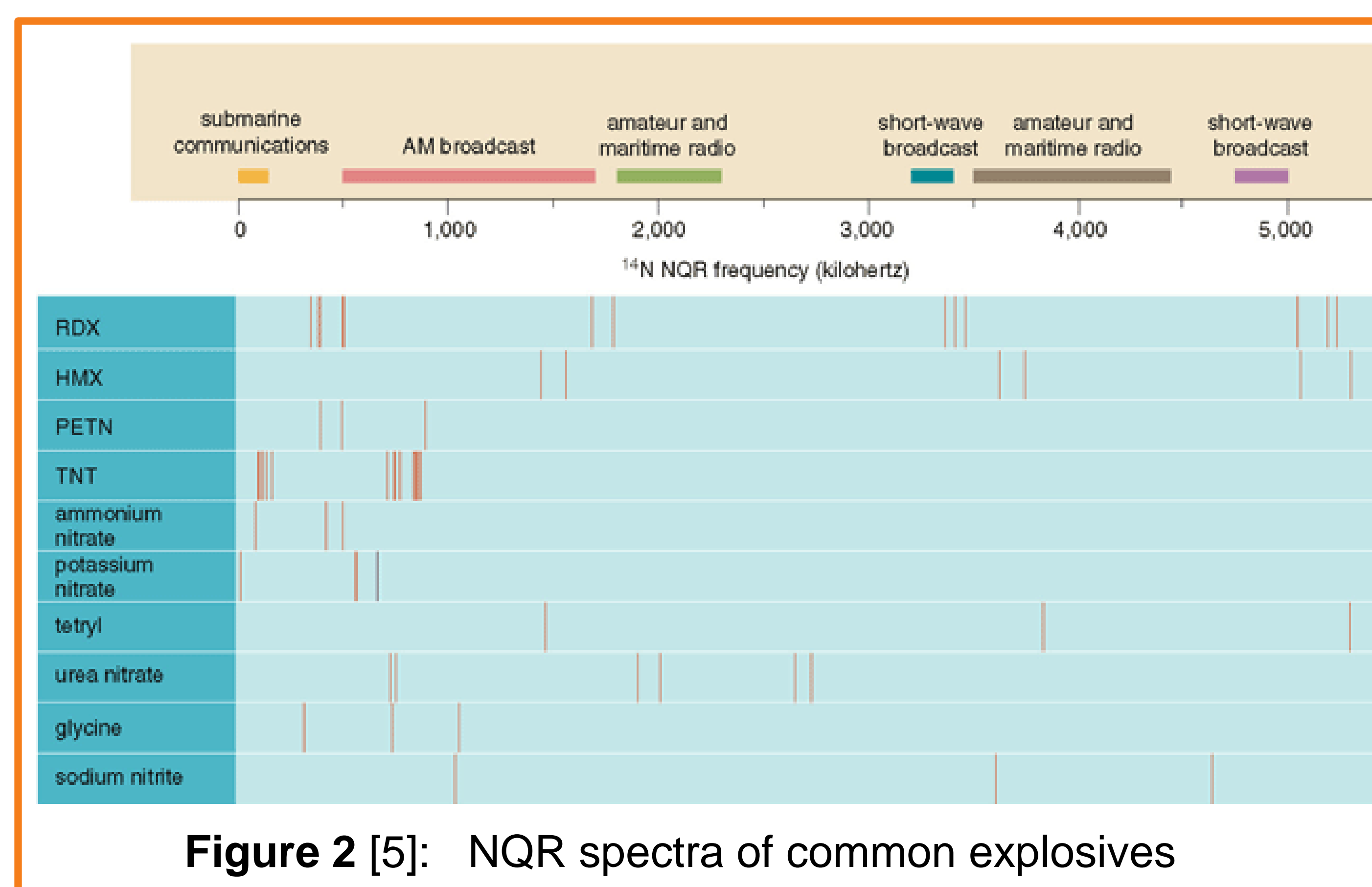

Figure 2 [5]: NQR spectra of common explosives

◊ **Low noise environment –** A common difficulty in applying NQR to applications such as mine-detection is that the resonance signal is difficult to pick out from background radiation. In a personal screening detector, this problem can be resolved cheaply by means of simple shielding such as an integrated Faraday enclosure.

◊ **Controlled temperature –** The line spectra of some explosives exhibit strong temperature dependence, which means that it is helpful for the sample temperature to be known. Implanted explosives are expected to be close to the human body temperature. Additionally, NQR techniques exist to deal with unknown temperature [6].

◊ **Few sources of ringing –** The presence of metallic objects within a sample can lead to magneto-acoustic and/or piezoelectric ringing that act as sources of noise to the detector [6]. In settings where metal detectors are in use, such as airport security, individuals being screened have little or no metal on them, eliminating this source of noise.

Results

Part of the field generated by an antenna will be reflected at the surface of an individual being scanned, and the transmitting portion will attenuate as it travels. At NQR frequencies, values of relative permittivity and conductivity within the human anatomy range across two orders of magnitude. This will give rise to complex scattering and attenuation of the field within the body.
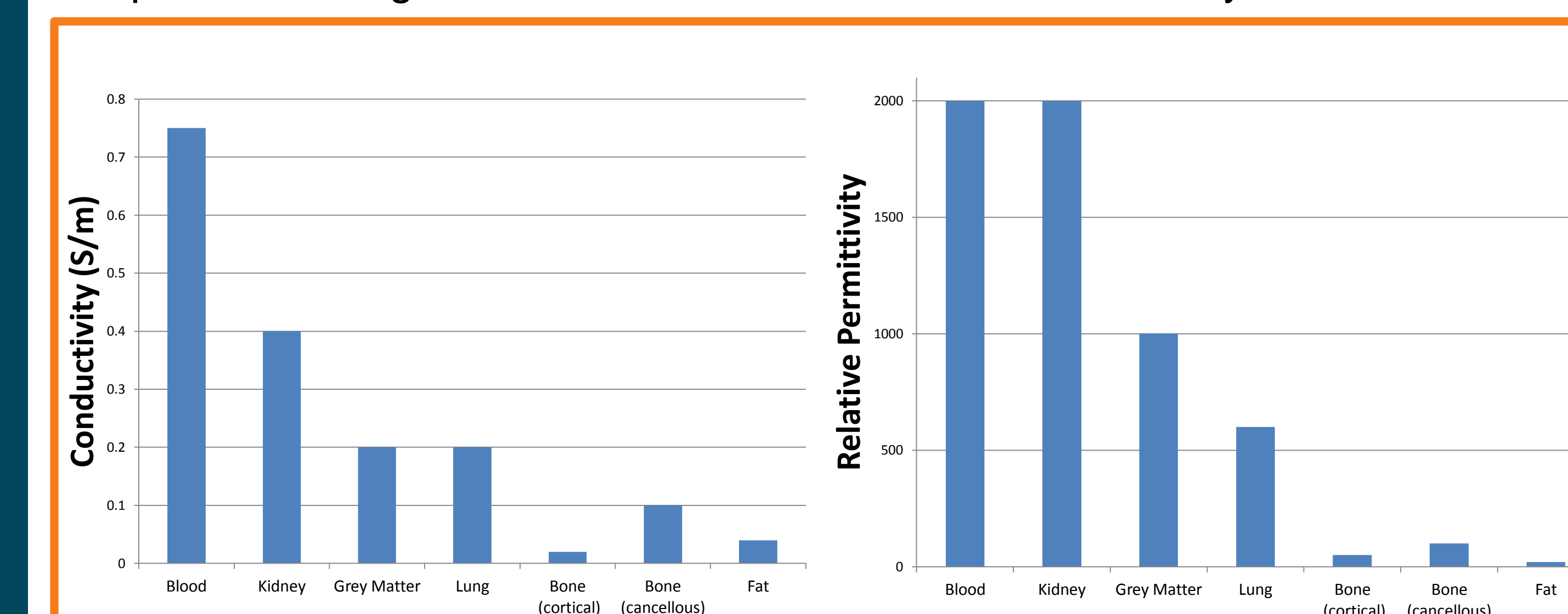

Figure 3: Approximate permittivity and conductivity of human tissue at 1MHz, a model frequency for NQR. Data from [7]

The results of a 2D FDFD simulation (Figure 4) show that the strength of a field produced by an antenna at 5MHz is up to 20% different from the field produced without the body being present (b). The body's presence also has a significant impact on phase (c).
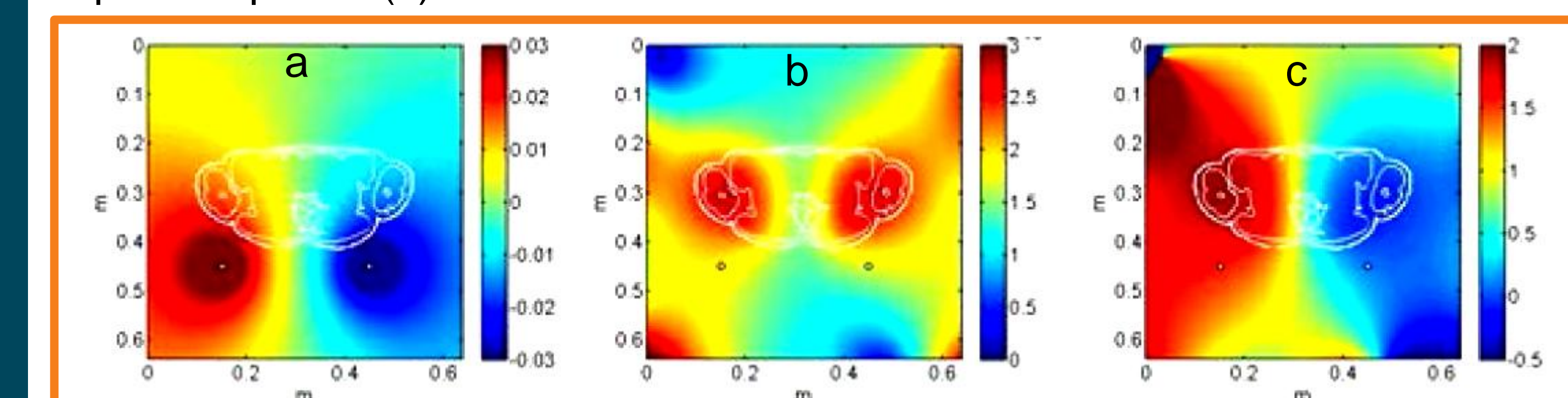

Figure 4: 2D FDFD simulation of 5MHz field interacting with human cross-section. a) Imaginary portion of total field, b) difference in magnitude between fields with torso present and absent, c) difference in phase between fields

Conclusion / Future Work

Several of the most common challenges associated with using NQR to find explosives appear tractable when searching for person-borne explosives. NQR may therefore provide a robust tool for preventing bombs from being brought aboard planes or into secure buildings. The fields used in NQR will be significantly affected by the presence of the human body, and more research is required to understand them. By adapting a 3D FDFD model for use with NQR frequencies, we will be able to examine the fields generated by an arbitrary antenna configuration. This will allow us to ensure that the nuclei of a hidden explosive are sufficiently excited by the antenna. Conversely, an arbitrarily placed explosive can then be treated as the signal source, and the antenna configuration can be evaluated for its ability to detect this signal. The proposed 3D FDFD model could also serve as a platform for evaluating and modifying other detection techniques for optimal use in personal-screening.

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