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Quantum Magnetics Targets Landmine Explosives Using Quadrupole Resonance

Recent studies show that Quantum Magnetics could be useful in detecting landmines through quadrupole resonance by emitting pulses of low-intensity radio waves that will return a characteristic radio signal to determine if an area is clear.

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Introduction

San Diego-based Quantum Magnetics did not intend to develop the world's best landmine detection technology, but it just might turn out that way. For the past five years, the company has been working to develop landmine detection technology that would be so specific and effective that it would minimize false alarms, thus saving lives and limbs of U.S. soldiers, citizens and landmine sweepers alike. Although Quantum Magnetics is also developing other security-related technologies for applications such as bomb, drug and concealed-weapon detection, it has continued to keep its core objective on course, and its scientists continue to concentrate on solving the most important ingredient of landmine detection—identifying buried landmine explosives used in mines quickly and with few false alarms. By targeting the specific molecules of explosives (such as RDX, tetryl, PETN, and the hardest to detect, TNT), Quantum Magnetics believes its sensors alone, or in combination with other detection devices, will be instrumental in removing the estimated 60 million to 110 million landmines abandoned throughout the world.

Quadrupole Resonance (QR) is the only chemically-specific technology that detects the presence of explosives in bulk. In cooperation with the Naval Research Laboratory and funded by the Federal Aviation Administration (FAA), DARPA, the U.S. Army and the Office of Naval Research, Quantum Magnetics has pioneered the use of QR explosives detection technology for landmine detection and aviation security. The Department of Defense clears lanes through minefields as quickly and reliably as possible under battlefield conditions. Combining a very high probability of detection with a very low false alarm rate is the best way to achieve this objective. Obviously, the same technology holds promise for humanitarian and commercial demining situations as well, situations where each and every mine must be found and removed.

The Landmine Problem

Presently, mine clearance operations remove approximately 100,000 mines per year. Some deminers use metal detectors and sharp, pointed sticks, euphemistically called probes. Other deminers use dogs, useful in detecting certain mines in certain locations. At this pace, however, it will require thousands of years to remove the millions of landmines in the ground today. This is unacceptable, considering there are about 26,000 people killed or maimed every year. In Cambodia alone, one out of every 236 people is an amputee.[1]

Current detection technologies are "clutter-limited," and deminers now endure between 100 and 1,000 false alarms for every mine found. All mines are plastic-cased or metal-cased; the former typically contain a small metal firing pin. Accordingly, metal detectors have been the chosen detection device. Metal-cased mines are typically much larger than clutter items (such as cartridge cases and shell fragments) and are easier to detect. But the metal detector set to alarm small metal firing pins within plastic-encased mines also alarms the smallest metallic clutter commonly found on battlefields. It is no mystery why there were 93 victims among the deminers in Bosnia, who were able to clear only 15 square kilometers in their first three years of work.[2] Fatigue and carelessness led to these casualties. Obviously, deminers, soldiers and citizens alike would welcome alternative technology that promises to detect only mines—large and small, or metal—or plastic-encased.

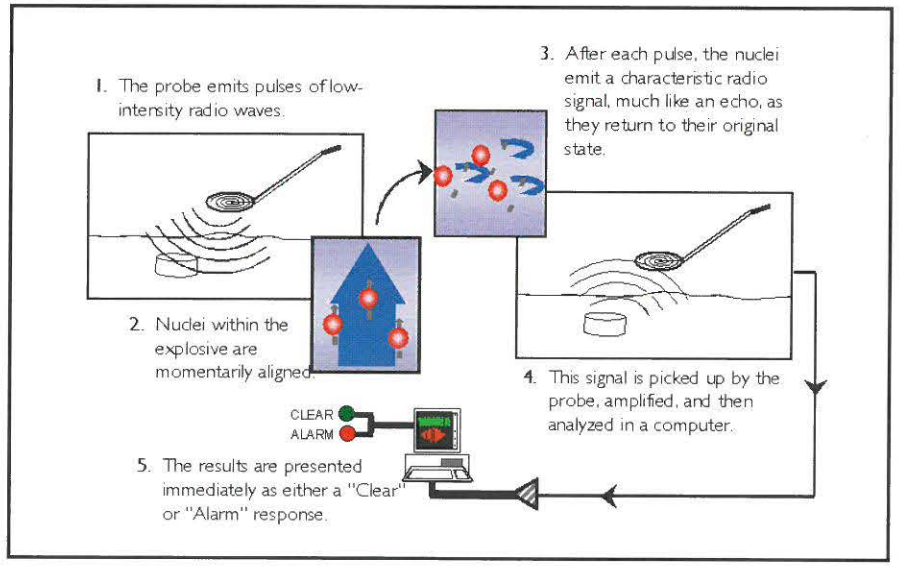


Figure 1. A schematic illustration of the QR method. Only specific nuclei within the target compound will respond to the initial radio pulses.

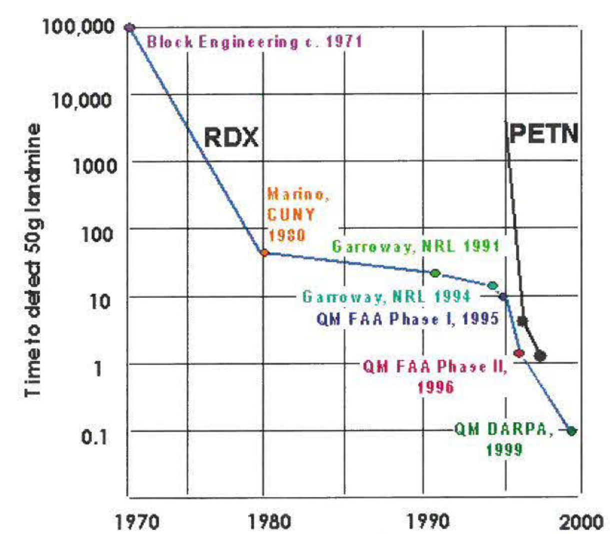
Quadrupole Resonance – How It Works

Quadrupole resonance is a low-cost, potentially man-carried variant of the magnetic resonance imaging (MRI) technology commonly used as a diagnostic tool in hospitals. Using low intensity radio waves (at frequencies between about 500 kHz and 5 MHz), QR probes certain molecular properties of items adjacent to the detection coil (see Figure 1). The probe emits pulses of low-intensity radio waves at a frequency determined by the target atomic species and its molecular environment. The radio waves momentarily disturb the alignment of the targeted nuclei. As the nuclei relax to their equilibrium condition, they emit their own signal, which is picked up and sent to a computer for rapid analysis. The signal emitted by each type of explosive is unique and readily distinguishable from those of harmless materials. Over 10,000 compounds have been investigated and no two have produced identical responses.

QR technology also responds to the presence of large metal objects, so it can detect both antitank (AT) and anti-personnel (AP) mines with an exceptionally high probability of detection while maintaining a very low false alarm rate. Since QR is chemically specific, the presence of other substances will not affect results adversely. And because QR detection is signal-to-noise ratio limited, not clutter limited, it is the only technology capable of resolving its own false alarms. Reducing clutter alarms by even as little as 70 percent to 80 percent would at least double the productivity of deminers and reduce the fatigue element they suffer when coping with the hundreds of false alarms they now endure.

Figure 3. A U.S. Marine Corps Gunnery Sergeant operating the QR detection probe on the test area at Eagle Base, Tuzla, Bosnia. The probe, a laboratory prototype, is wrapped in plastic to protect it from the rain. A tether links the probe to a rack of electronics on the truck in the background.

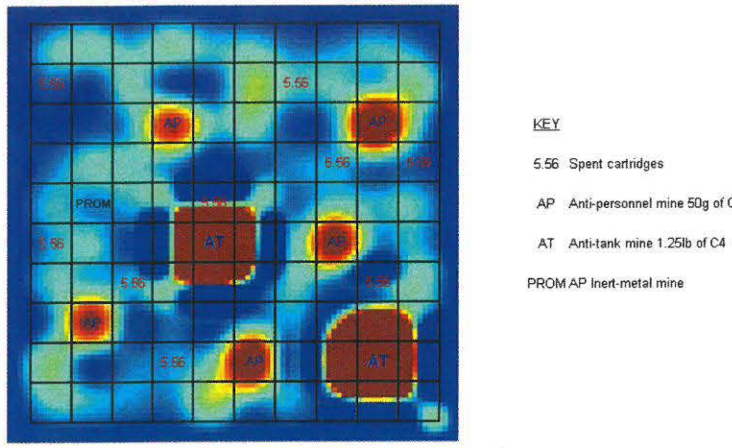
QR was first investigated in the early 1970s for the purpose of landmine detection during the Vietnam War. At that time, the sensitivity of the technique was inadequate for operational use. In the intervening decades, several research groups in the United States, as well as in other countries, have contributed to a dramatic improvement in sensitivity. Figure 2 illustrates the improvement, presenting the time required to detect a mine with 50 grams of explosive as a function of the year in which the measurement was made. The figure identifies key milestones in the dramatic progress of QR research.



(Above) **Figure 2.** Improvement in explosives detection using QR (1970-2000).

Test Results

Quantum Magnetics has already demonstrated the potential of its QR technology in a series of military-sponsored blind



(Right) **Figure 4.** False-color plot of QR signal amplitude (signal grows from blue to red) over the Eagle Base test area. The key describes the objects buried in the test area. Every explosive charge shows a strong QR signal (red), without any strong signals elsewhere.

tests at Camp Pendleton (CA), Fort Leonard Wood (MO) and one specially earmarked area set aside for such tests near Tuzla, Bosnia.

In the Bosnia tests, the QR electronics were mounted on a military vehicle and connected to the hand-held QR scanning coil by a long tether. In a 10 by 10 foot square patch of ground at Eagle Base, Tuzla, the U.S. Army buried seven lumps of military C4 explosive, containing the active chemical RDX and a metal-cased PROM mine (inert dummy). The Army also buried eight spent cartridges (5.56 mm) to simulate metallic clutter usually encountered on a battlefield.

A military demining expert, who had not participated in the burial process and did not know where the objects were, operated the prototype QR system (Figure 3). He detected all the explosive charges using a QR probe, and the metal-cased inert mines using the probe's metal detector, without a single false alarm from the spent cartridges. Before his detections were independently verified, he repeated the scan of the test area using a standard-issue AN/PSS-12 metal detector. As expected, he did not detect the lumps of explosive, which contained no metal. He recorded, however, a total of 37 "hits" in the same area—29 more than the number of known metal clutter objects buried there.

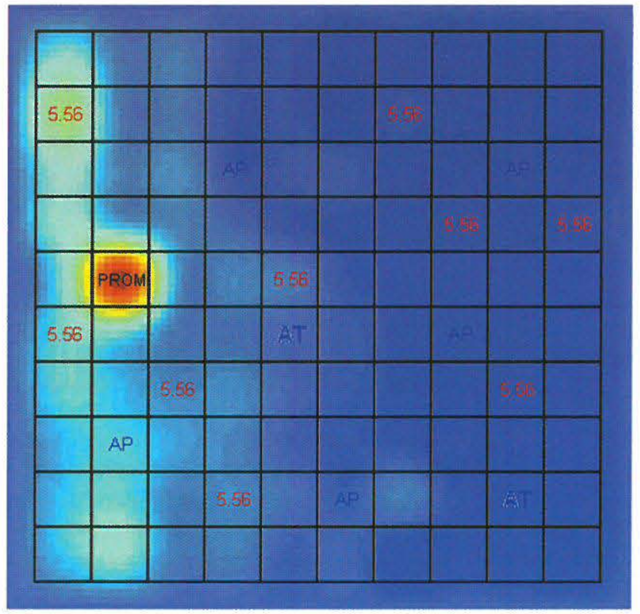


Figure 5. False-color plot of the metal detection signal amplitude from the QR probe (signal grows from blue to red). The metal-cased PROM mine signal exceeds the detection threshold, but none of the spent cartridges do. (refer to key in Figure 4)

The Bosnia tests took place in June 1999. By October in the same year, Quantum Magnetics had developed the ability to detect TNT (contained in the majority of landmines worldwide) sufficiently to test it at a test range in Fort Leonard Wood, MO. The results in figure six reportedly represent the first-ever QR detection of TNT landmines in the field.

QR is User Friendly

As the QR detection probe investigates a given area, results are presented as a simple red light/green light display to indicate either the presence or absence of a mine. QR systems require no calibration or special maintenance and are ruggedly designed to withstand many hours of uninterrupted use. Importantly, the technology is safe and does not use ionizing radiation, radioactive sources or strong magnetic fields.

Quantum Magnetics is currently developing its QR technology into a man-carried backpack configuration, as required by the Office of Naval Research for eventual use by the U.S. Marine Corps. Once this work is completed, the 35-pound detector, including probe, electronics and batteries, will be capable of scanning all variations of terrain encountered by deminers, military or civilian.

Supported by the U.S. Army, Quantum is also developing its technology into a vehicle-mounted configuration for use in detecting antitank (AT) mines in roads. A confirmation sensor, designed to validate or clear alarms produced by other sensor technologies, will be tested this year. A primary scanning sensor will be developed and tested in 2002.

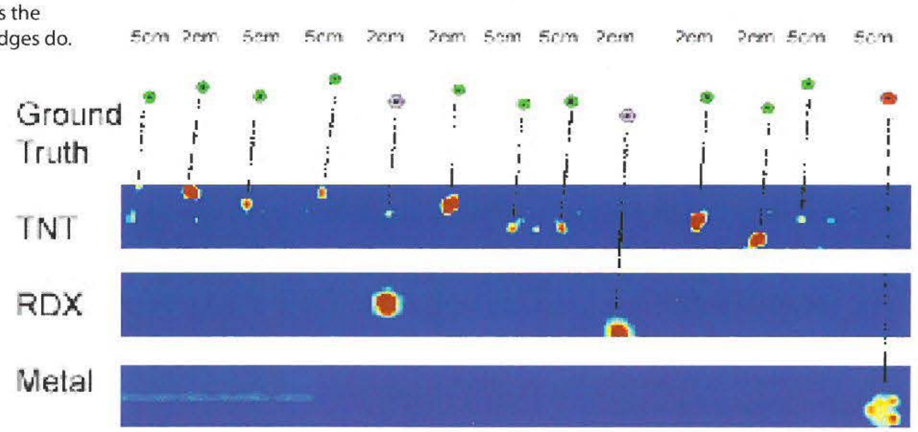


Figure 6. False-color plot of the QR signal amplitude (growing from deep blue to red) for TNT (top), RDX (center) and metal (bottom) over an antitank mine lane at Ft. Leonard Wood, MO. Ground truth is color-coded, with TNT mines in green, RDX in purple and the metal-cased mine in red. Mines were buried at operational depths. Each mine is associated with a strong signal; there are no strong signals where there are no mines.

Remaining Challenges

With all these advancements, however, QR is not yet ready for prime time. Quantum Magnetics is continuing to perform research to further improve detection, as are other organizations domestically and abroad. Some of the challenges that must be overcome include the following:

- *Improved sensitivity to TNT.* At the moment, detecting the smallest anti-personnel (AP) mines at the deepest depths, within practical time limits, represents an unsolved problem. Learning more about how the TNT nuclei interact can help increase the signal obtained per unit time and thus achieve the required performance.
- *Detecting mines while on the move.* At the moment, the detector must remain stationary over a patch of ground while making a measurement. The measurement can last anywhere from a fraction of a second to over a minute, depending on the amount, type and depth of explosive that must be detected. Technology must be developed that enables scanning while in motion, without undue loss of signal.
- *Reducing the size, weight and power of QR electronics.* Two years ago, the electronics needed to perform the QR measurement occupied two racks of electronics, weighing well over 200 pounds and drawing kilowatts of electric power. Today, they occupy a single small rack and draw hundreds of watts, a substantial improvement. Further development and engineering are needed to reduce the system to a size and weight that can be readily carried by a single individual.
- *Mitigating the effects of radio frequency interference.* Traditional QR systems are enclosed inside metal containers to shield unwanted radio signals from the outside. Such an approach is obviously impractical in a landmine detector. Methods have been developed to mitigate external interference, but further improvements will help solve all the other challenges noted above.

Future Demining Strategies

Quantum Magnetics is now working on the premise that using QR explosives detection to find plastic-cased mines and QR metal detection to locate metal-cased mines results in a system with high detection and low false alarm rates. In fact, portable QR systems could clear between 60 percent and 95 percent of today's false alarms, eliminating the dangerous and time-consuming step of probing the ground, thus improving safety and increasing the area cleared per unit of time per deminer. Using QR detectors as confirmation sensors would significantly reduce metal detector false alarms and subsequent probing with sticks to a minimum. Other efforts include work to suppress sources of "noise," such as electronic amplifier noise and external radio frequency interference in the QR measurement. As the company works to improve its detection capabilities, it is also engineering a backpack-configured detection system that can be carried by military deminers. In a parallel effort, Quantum Magnetics is engineering vehicle-mounted systems for both primary and confirmation scanning. Eventually, with suitable modification, both types of systems may prove to be valuable new tools in the arsenal of humanitarian as well as military mine clearers.

In summary, Quantum Magnetics' success thus far in blind test environments indicates its QR-based technology will soon be capable of detecting landmines better, faster and less expensively than alternative demining processes. With government support, progress is being made every day to detect the smallest mines at the deepest depths in the shortest scanning time possible. ■

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*All photos and graphics courtesy of the author.

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