

Nuclear Quadrupole Resonance (NQR) for Detecting Explosives (and some drugs)

... a commercialisation story



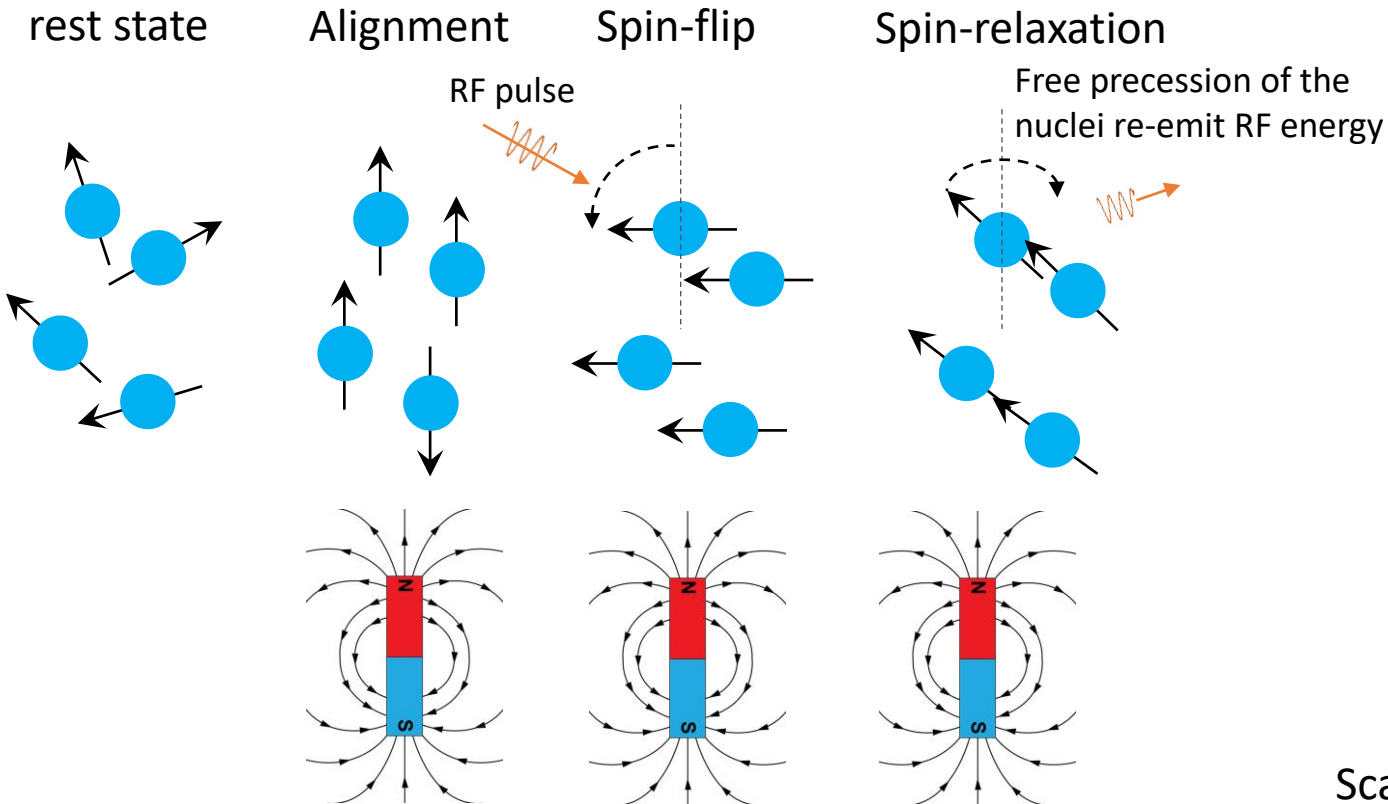
Cannington, Western Australia

2005 - 2008

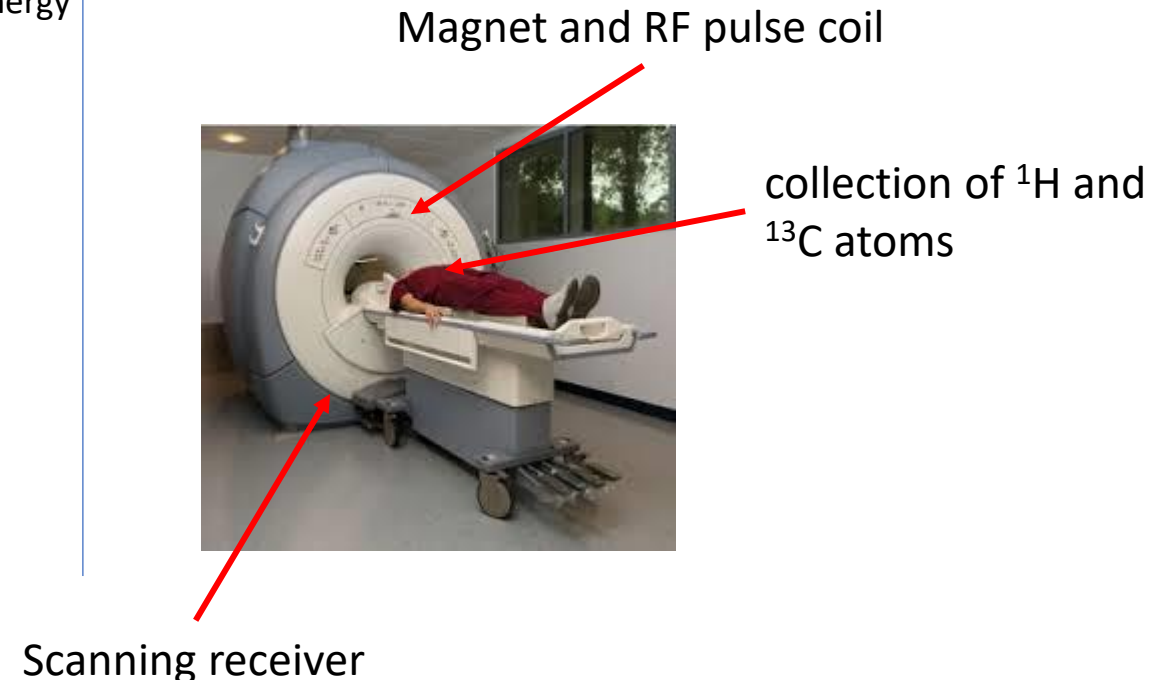
Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI)

- Atomic nuclei with an odd atomic number have a non-zero “nuclear spin” and hence a net magnetic dipole moment (^1H , ^{13}C for example)

NMR

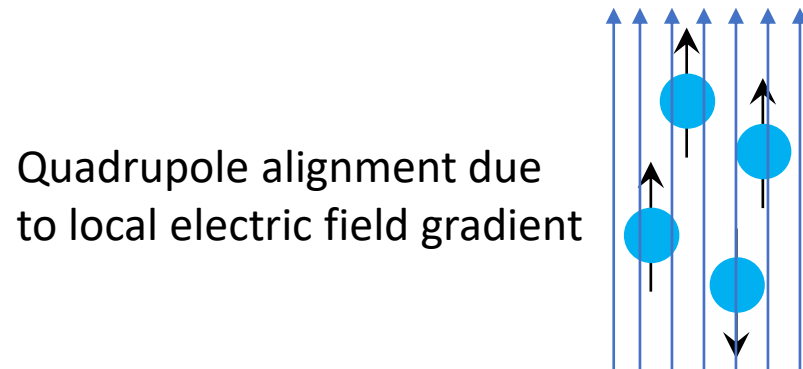


MRI



Nuclear Quadrupole Resonance (NQR)

- NQR exploits the presence of a nuclear **quadrupole** moment present in many atomic nuclei (eg ^{14}N , ^{35}C)
- Nuclear spin states determined by **electrostatic** interaction of the quadrupole moment with the external electric field gradient

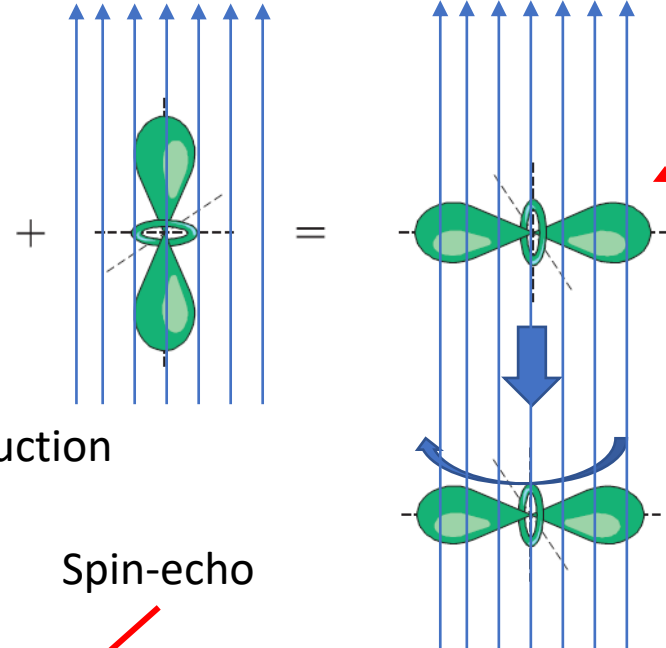


- NQR can be roughly thought of as **NRM (MRI) without the magnet**
- NMR not very sensitive to surrounding chemistry, NQR **extremely** sensitive

NQR

local electrostatic field gradient

Atomic nucleus with a quadrupole moment (eg ^{14}N , ^{35}C)



*Image adapted from: Garroway
Alternatives for Landmine Detection
Rand Corporation Report MR-1608, 2003*

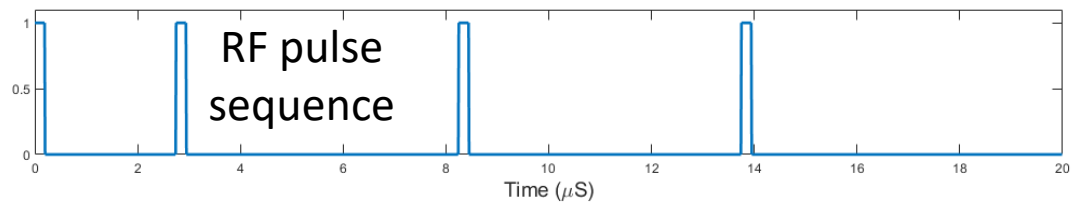
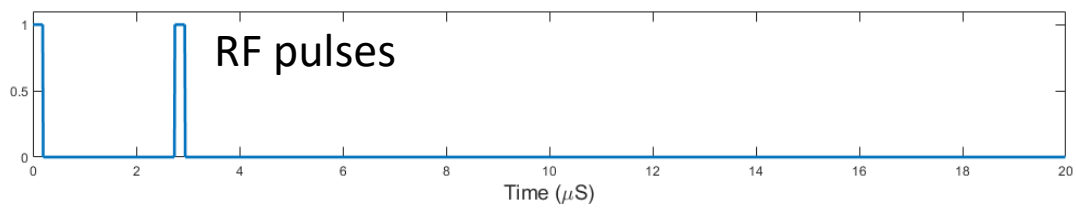
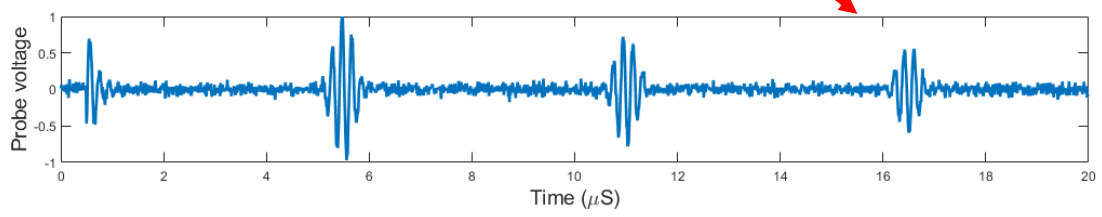
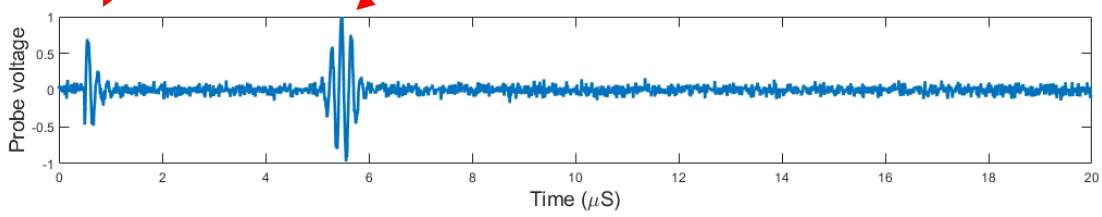
Free precession of the nuclei re-emit RF energy



Free (precession) Induction Decay (FID)

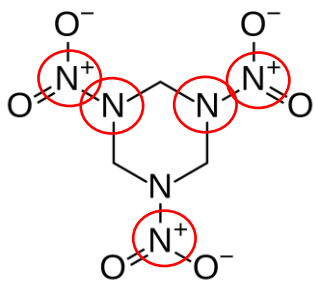
Spin-echo

Multiple decaying spin-echo's

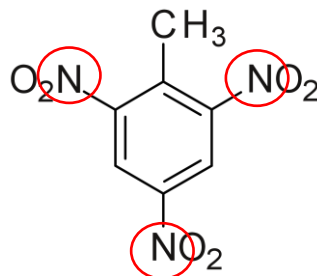


Crystalline High Explosives

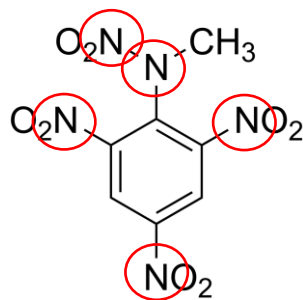
Military



RDX

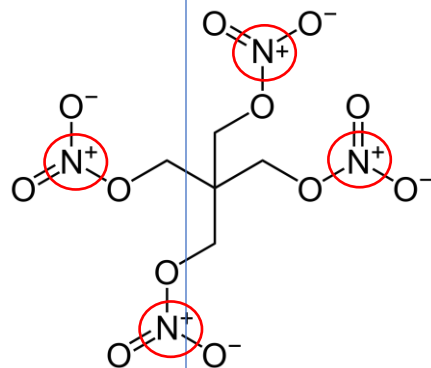


TNT



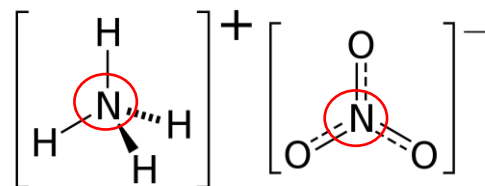
Tetryl

Mining/Commercial



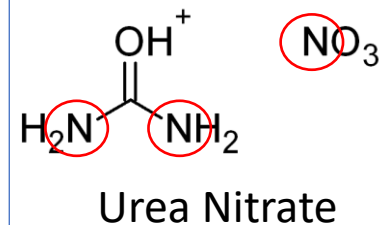
PETN

¹⁴N



Ammonium Nitrate

Mainly terrorist uses (IEDs)



Urea Nitrate

Plastic explosives:

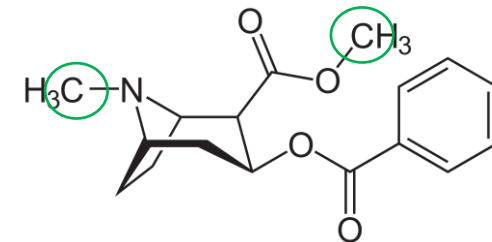
C4 (RDX)

Semtex (PETN, RDX)

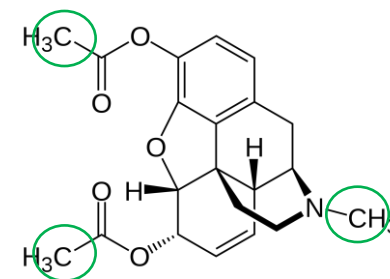
Detasheet (PETN)



Illegal Drugs



Cocaine



Heroin

³⁵C/³⁷C

Why use NQR?

- NQR **extremely** sensitive to surrounding chemistry
- Specific to the chemistry of an explosive **regardless of how it is packaged**
- Much early interest in NQR for finding and clearing landmines

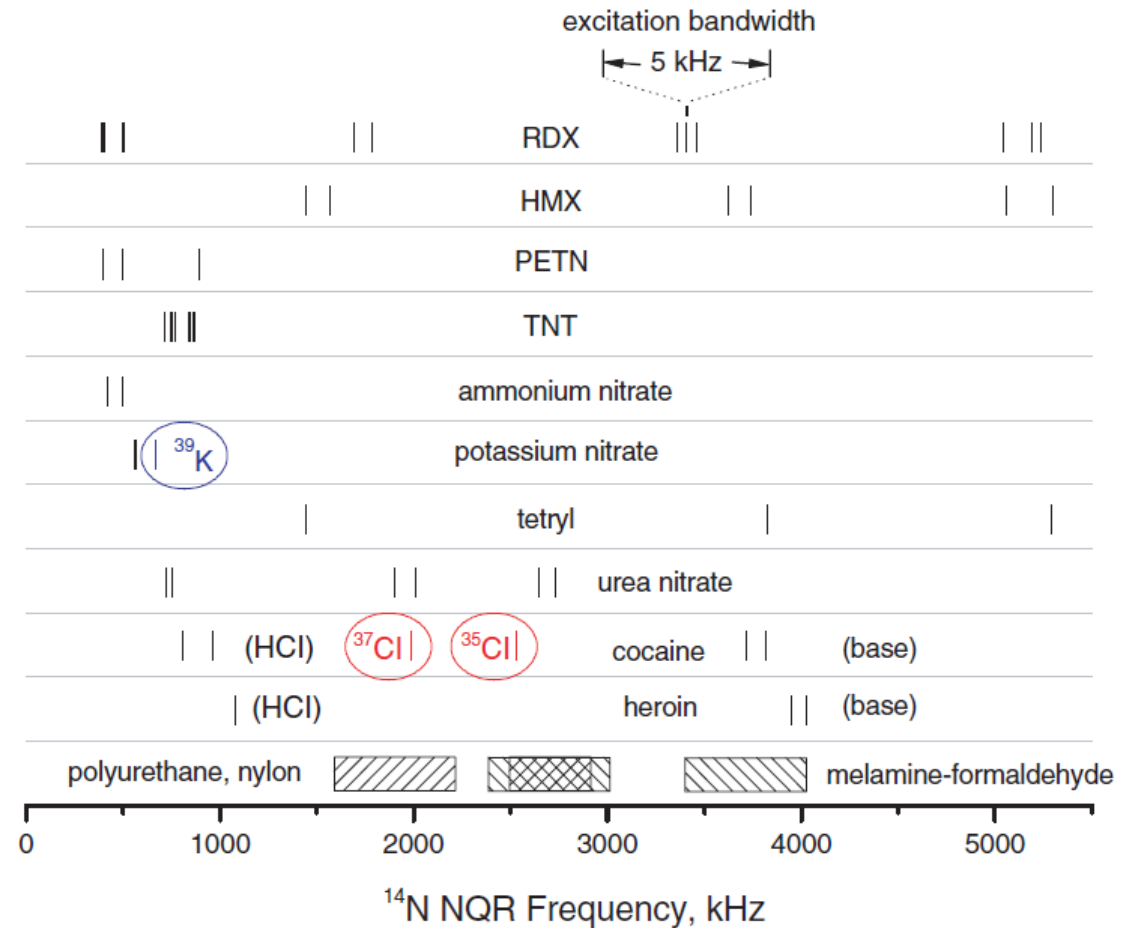


Image: Garroway
 Alternatives for Landmine Detection
 Rand Corporation Report MR-1608, 2003

Drawbacks

- Magneto-acoustic ringing
- Piezo-electric ringing (MAPER)

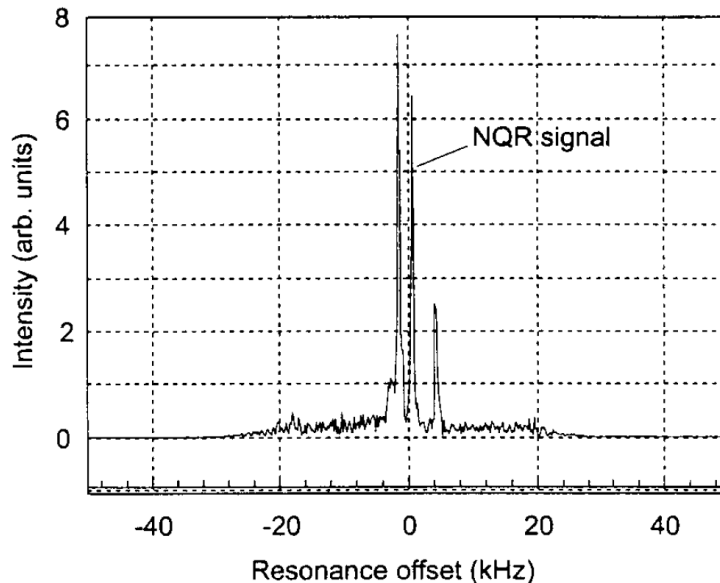
- Electro-mechanical effects
- Can be much larger than the NQR response signal



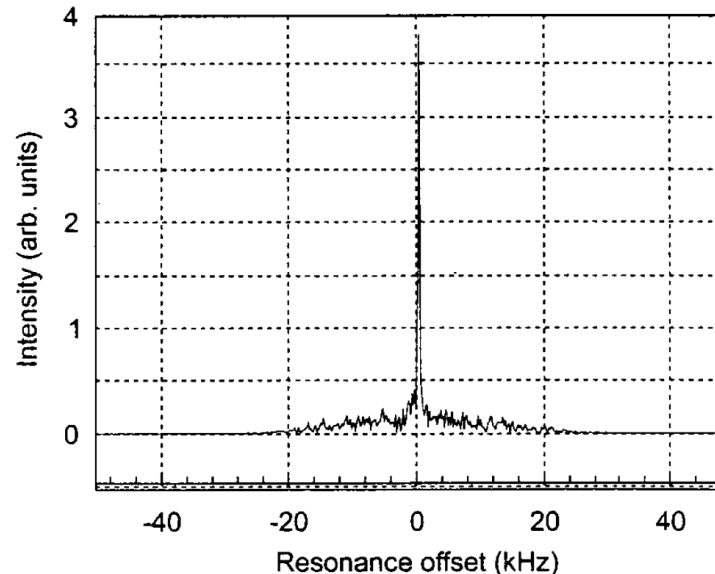
Multi-pulse sequences to cancel out MAPER effects and resolve the NQR response

Example: 30 g of RDX ($f = 5.192$ MHz) in the presence of a nickel-plated washer

Simple spin-echo sequence



Multi-pulse sequence



*Images: Mikhaltsevitch, Rudakov, Flexman, Hayes, Chisholm
Multipulse Sequences for Explosives Detection by NQR under Conditions of Magnetoacoustic and Piezoelectric Ringing*

Applied Magnetic Resonance, Springer-Verlag 2004

QRSciences: Primary Inventors and Patent Holders

- Vassily Mikhaltsevitch
- Taras Rudakov
- John Flexman
- Peter Hayes
- Warrick Chisholm

1. Method and Apparatus for Improving the Detection of Nuclear Quadrupole Resonance Signals In Coherent Noise (20070279057)
2. Q-factor switching method and apparatus for detecting nuclear quadrupole and nuclear magnetic resonance signals (20070040556)
3. Signal processing for detection of nqr signals (20070018644)
4. Probe coil for detecting nqr-responsive materials in large volumes (20060145697)
5. Pulse sequences for exciting nuclear quadrupole resonance (20060091883)
6. Scanner for nuclear quadrupole resonance measurements and method thereof (20060012366)
7. Pulse sequences for exciting nuclear quadrupole resonance (20050162163)
8. Transmit-receive coil system for nuclear quadrupole resonance signal detection in substances and components thereof (20050146331)
9. Q-factor switching method and apparatus for detecting nuclear quadrupole and nuclear magnetic resonance signals (20050116714)

How does the NQR machine work?



Image: Rudakov
Magnetic Resonance Detection of Explosives and Illicit Materials, book chapter

Scan range: 400 kHz – 5.5 MHz

Scan rate: 200 bags per hour

Multiple pulse sequencer to mitigate against magneto-acoustic and piezo-electric ringing effects (Nickel-plated objects in particular)

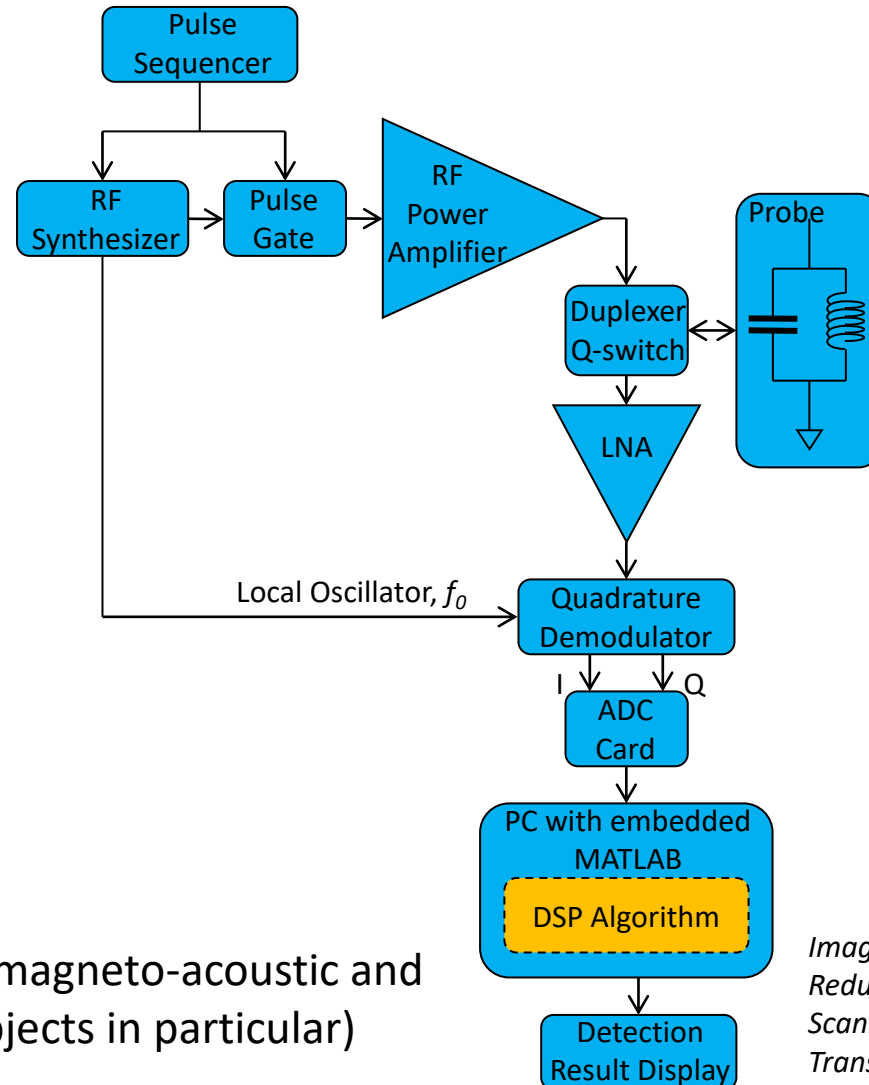


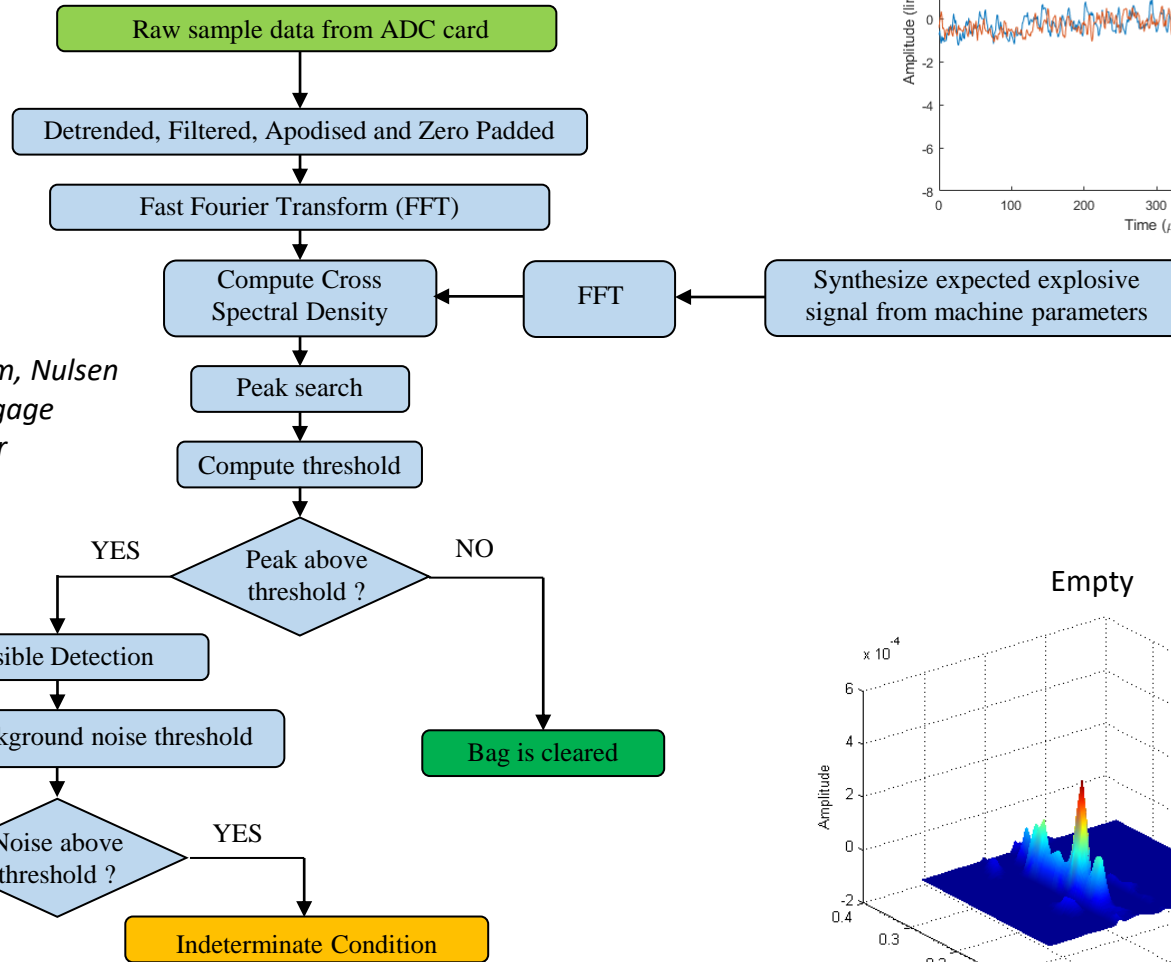
Image: Rudakov
Magnetic Resonance Detection of Explosives and Illicit Materials, book chapter



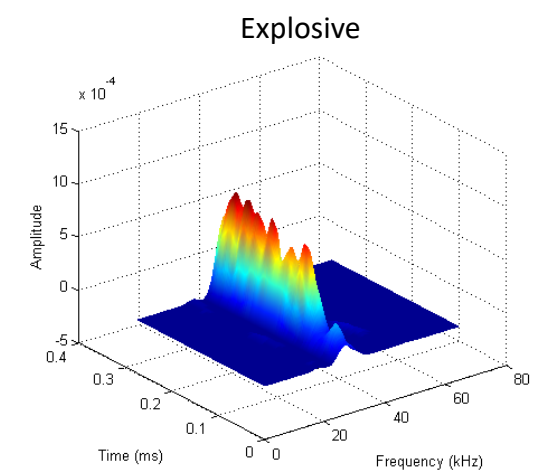
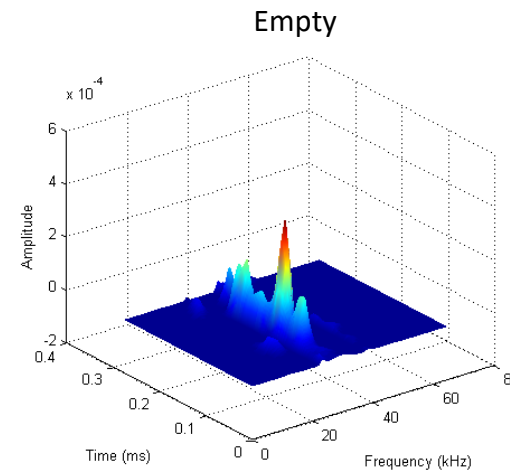
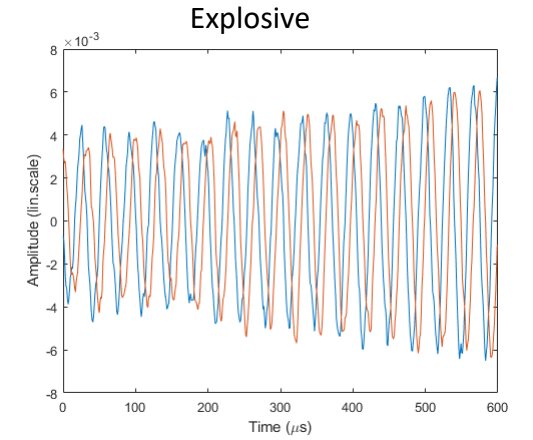
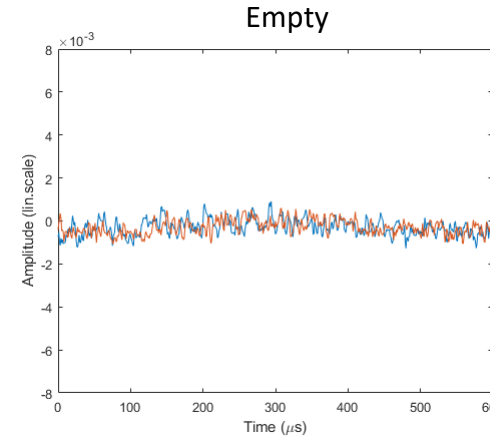
RF switch and capacitor for tuning the probe coil.

Image: Tuthill, Chisholm, Nulsen
Reduced False Alarm Rate in QR Baggage Scanners using the Short Time Fourier Transform, internal report

DSP Algorithm



*Image adapted from: Tuthill, Chisholm, Nulsen
Reduced False Alarm Rate in QR Baggage
Scanners using the Short Time Fourier
Transform, internal report*



Receiver Operating Characteristic (ROC) Curves

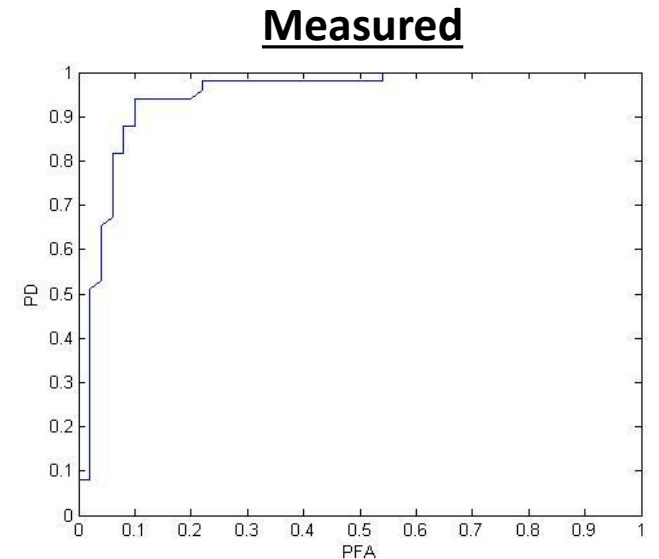
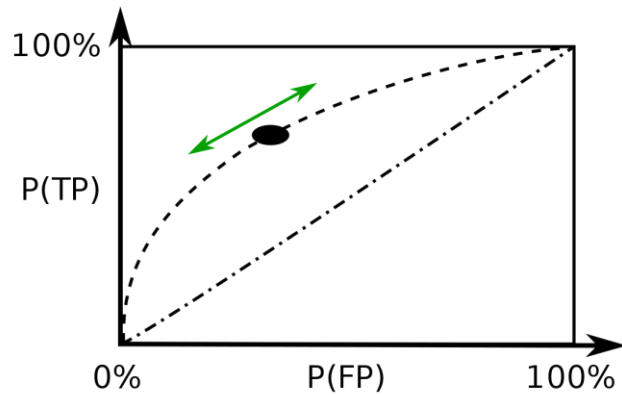
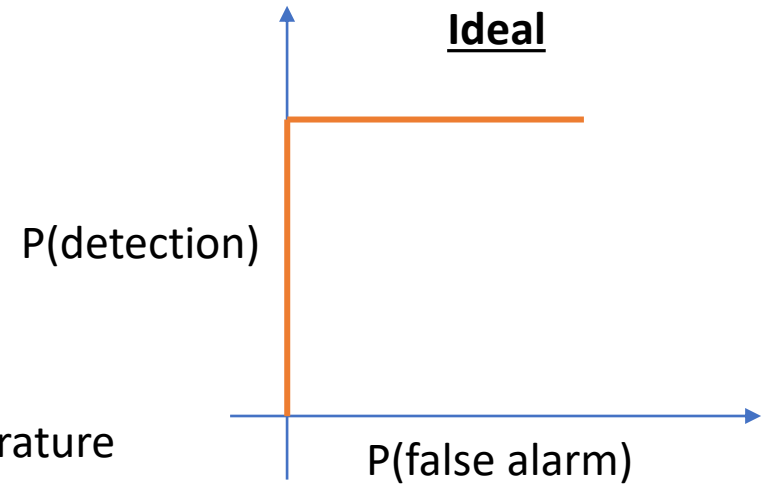
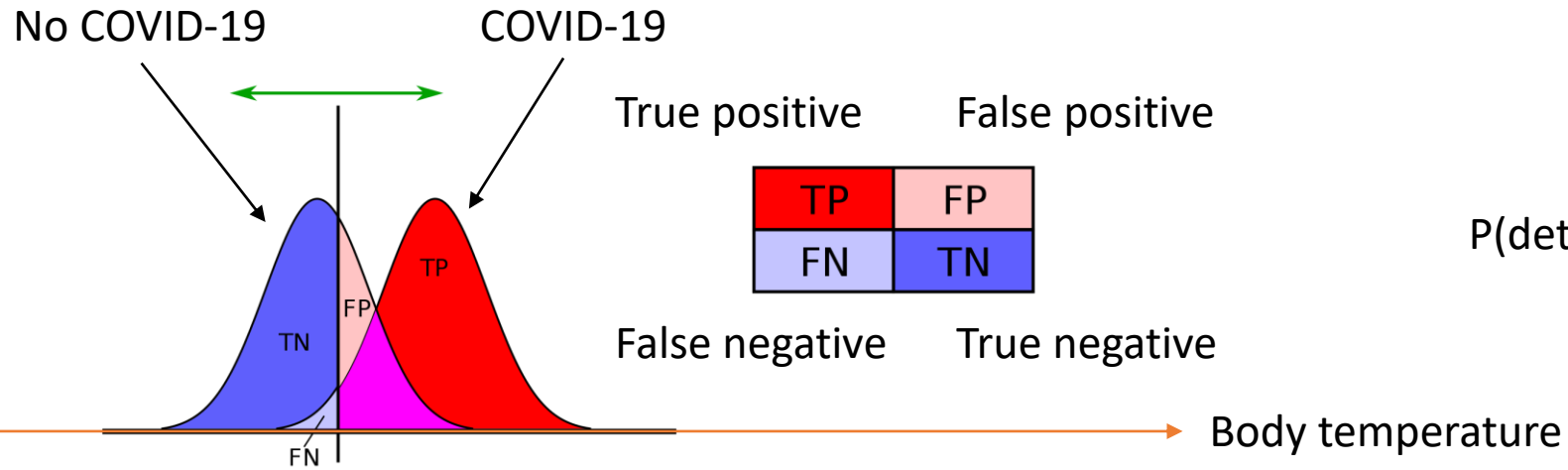


Image adapted from: Wikipedia
https://en.wikipedia.org/wiki/Receiver_operating_characteristic

What happened to QRSciences?

- Significant challenges with selling into large airports and government bodies (e.g. US Transportation Security Administration)
 - Relatively low throughput
 - Relatively high false alarm rate
 - Large physical size
 - High manufacturing cost
 - Requirement for manual calibration
- Sold to Rapiscan Systems in 2010



- There's a **long** way and a lot of luck between a great idea and commercial success!

Thank you

CASS

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<https://www.csiro.au/en/Research/Astronomy>

