Pushing the boundaries of UHF NMR Magnet Technology

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Bruker Corporation

**Bruker Scientific Instruments (BSI)**

- **Bruker MAT** – X-ray, optical emission spectroscopy, atomic force microscopy and stylus and optical metrology instrumentation
- **Bruker BioSpin** – Magnetic resonance spectroscopy and imaging (NMR, MRI, EPR)
- **Bruker Daltonics** - Mass spectrometry, gas chromatography and CBRN detection
- **Bruker Optics** – Optical Vibrational Spectroscopy (FT-IR, NIR & Raman)

**Bruker Energy & Supercon Technologies (BEST)**

- Superconducting magnets, high and low temperature superconductor wire development and manufacturing
Bruker Magnet Production Sites

750 – 1000 MHz NMR Magnet Production Karlsruhe, Germany

Horizontal bore MRI and FTMS Magnet Site Wissembourg, France

300 – 750 MHz NMR Magnet production Fällanden, Switzerland
High Field NMR Milestones

Magnet specifications in persistent mode:
- NbTi single filament (1960s)
- NbTi multi filament (1970s)
- Nb_3 Sn (1980s)
- (Nb,Ta)_3 Sn (1990s)
- Nb_3 Sn (2000s)
- NbTi (2010s)
- HTS (Nb,Ta)_3 Sn (2020s)

Bruker BioSpin
NMR enables the non-destructive and quantitative investigation of molecular structure, interaction, kinetics and the composition of mixtures of biological or synthetic solutions or composites.
Key Technologies

- 2K cooling
- Active shielding
- Active cooling
- Artifact suppression
- Coil technology
Today's most advanced Ultra High Field Magnets

950 MHz HR-NMR

15 T FTMS Magnet

Most compact 850 MHz

Photo courtesy of Korea Basic Science Institute (KBSI)
UltraStabilized™ Sub-cooling Technology

- Long term stable magnet
- Highest field strengths
- Increased magnet stability
- Higher safety margins
- Lowest drift rates
- Easy helium refills

- Patented technology
- Pioneered by Bruker
- Proven track record
- Over 180 systems installed

UltraStabilized™ technology delivering unique performance, stability and safety
Introduction of high current designs and rectangular wire technology

**High current design**

\[ I_M = 2 \cdot I_0 \]

- rectangular wire
- conductor area = 4 mm²

**Low current design**

\[ I_M = I_0 \]

- round wire
- conductor area = 2 mm²
Advantages

- Higher current results in a larger wire cross sections
- Suitable for rectangular wire
- Better winding chamber filling factor
- Less insulation material in winding chamber
- Better control of forces
- Enables highest fields

(NbTaTi)$_3$Sn-conductor

(NbTaTi)$_3$Sn Bundle

Cu

Nb

2 mm

1 mm

NbTi-conductor
UltraShield Technology

Inner sections (Blue): main field coils
Outer sections (Red): shielding coils

- Significantly smaller stray fields
- Improved screening against external field perturbations
Minimizing required Lab Space

800 MHz UltraStabilized

800 US²™

Bruker BioSpin
Ascend 800/850 - Minimum Space Requirements

A - Spectrometer  D - UPS
B - BMPC        E - Working Table
C - Pumping Unit F - BCU 05 Unit

A - Spectrometer  D - UPS
B - BMPC II      E - Working Table
C - Cryoplatfrom F - BCU 05 Unit
The Ascend 850 MHz – Fits in Single Story Lab
EDS™: External Disturbance Suppression
Example: Ascend 850

External Disturbance Suppression

Ext. Disturbance

Frequency response
Bruker Ultra High Field Magnets

WB (89 mm)

SB (54 mm)

800 18.8
850 20.0
900 21.1
950 22.3
1000 23.5

MHz

Total: over 180 installations
The US² Series
850 WB, 900, 900 WB and 950

- Advanced active-shielding delivering small stray fields
  - 5 Gauss horizontal: 3.3 m
  - 5 Gauss vertical: 4.6 m
- Reduced overall system footprint for increased siting flexibility

900 US², Courtesy of National Institute of Standard and Technologies (NIST)

900 WB US², Courtesy of KAUST

950 US², Courtesy of University of Maryland at Baltimore
Ascend™ 800 and 850
Most Compact Ultra-High Field Magnets

- **Fit in a single-story lab**, minimum ceiling height of only 3.6 m (12’)
- Total weight: 3,500 kg, **suitable for upper floors**
- Most advanced active-shielding delivering:
  - **minimum stray fields**, 5 Gauss at 1.6 m radially and 2.7 m axially from the MC (850 MHz)
  - **99% suppression of external field disturbances**
- **Over 40 x Ascend 800/850 installed** at customer sites worldwide

300 ft² area

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Ascend 850, Courtesy of University of Delaware

Ascend 850, Courtesy of University of Minnesota

Ascend 850, Courtesy of MUSC, Charleston, SC
Ultra-High Field (750 – 1000 MHz)

More than 180 installations worldwide

11 x 750 MHz installations

130 x 800 – 850 MHz installations (including 40 compact)

35 x 900 – 950 MHz installations
MRI Product Line

- Icon™
- ClinScan®
- PharmaScan®
- BioSpec®
- Research UHF Systems

1T, 4.7T, 7T, 9.4T, 11.7T, 17.2T
World’s Highest Field Preclinical MRI system

BioSpec® 172/26

- *In vivo* imaging at 17.2 T
- Sub-cooling technology delivers ultra-high magnetic fields
- Compact magnet design

Courtesy: D. Le Bihan, NeuroSpin, Paris, France
21.0 T / 11 cm FT-ICR Magnet

- Project awarded by NHMFL at Florida State University
- Highest resolution mass spectrometer
- Special stray field features designed for ICR application
- Sub-cooled and refrigerated magnet with low He consumption
Examples of Special HF Magnets

Actively shielded laboratory magnet
21 T/64 mm or 20 T/80 mm

9.7 T gyrotron magnet for DNP
Examples of Special HF Magnets

16 T split-coil actively shielded magnet
- Highest field for Neutron scattering

12 T EPR magnet – cryogen free
AVANCE 1000
World’s First 1 Gigahertz NMR Spectrometer

- World’s first, standard-bore, high homogeneity 1 GHz NMR magnet
- Persistent superconducting magnet
- UltraStabilized™ sub-cooling technology
- Magnetic field strength of 23.5 T
- Standard bore size of 54 mm
- The high field strength and high field stability in combination with the first 1 GHz 5mm triple-resonance CryoProbe™ enables unique 1 GHz NMR applications
- Installed in Lyon
New Superconductors for Ultra High Field Magnets

Need to have:
- High critical current at $B > 23.5$ T
- High mechanical strength

Potential new conductors
- BSCCO: Bi 2223 or Bi 2212 (1. generation)
- YBCO Coated Conductors (2. generation) show good promise for even higher fields

Courtesy of Centre de RMN à Très Hauts Champs’ Lyon, France
Yttrium Barium Copper Oxide (YBCO) Coated Conductor

- YBCO (~1 µm)
- YSZ Buffer (~1.5 µm)
- SS-Substrate (100 µm), non-magnetic
- CeO$_2$ Buffer (~0.05 µm)
- Au Protective/stabilizing layer (~0.2 µm)
- Cu Shunt layer (~20 µm)
Bruker Energy & Supercon Technologies (‘BEST’)

BEST HTS Material Development and Production

- **Production of long length, 1G HTS, Bi2223** for generators and future energy related applications

- **Installation of machinery for long length** (~ 2km) and **high volume coated YBCO** conductors in progress
1.2 GHz Project

- Bruker has started development of 1.2 GHz before completion of the 1 GHz project
- 1.2 GHz development is part of the continuing co-operation with KIT* (Karlsruhe Institute of Technology)
- KIT has been our Ultra High Field development partner for over 25 years

*former name: Forschungszentrum Karlsruhe

\[ \text{YBCO} \quad \text{Nb}_3\text{Sn} \quad \text{NbTi} \]
1.2 GHz Challenges

HTS conductors need to:

- Overcome intrinsic resistivity
- New solenoid winding technology
- Quench protection
- Long term stability at RT and 2 K
- Two dimensional properties
- Long lengths (min. 1000 m)
- Continuous reproducible conductor quality
- Joint technology

All issues must be solved to design a long term stable and reliable NMR magnet!
When will 1.2 GHz become reality?

Magnets having full NMR specifications in persistent mode