

Exploring Energy Sustainability and Efficiency at 21.1T MRI/NMR magnet

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Introduction

Magnetic Resonance Imaging (MRI), an application of Nuclear Magnetic Resonance (NMR) Spectroscopy, is widely used to study biological structures like tissues and organs with the help of strong magnetic fields and Radio Frequency (RF) pulses. NMR spectroscopy is used to determine the chemical and molecular structure of solid or liquid samples, while MRI is utilized as a non-destructive diagnostic tool for imaging the brain, heart, and muscles.

To conduct MRI/NMR experiments and process the data, we need supporting equipment such as transceivers, RF amplifiers, gradient amplifiers, shim amplifiers, chillers, and acquisition control systems. Not all instruments need to be running during a particular experiment. For example, while performing NMR, we don't need to use the gradient amplifiers, animal monitoring systems, and chillers that are specific to MRI experiments.

Running these systems 24/7 could lead to energy waste and negatively impact the environment with increased CO₂ emissions. Although there are studies targeted towards clinical MRI 3T systems [3], data on ultra-high field MRI/NMR systems like the 21.1T (Fig 1) , the world's strongest MRI magnet used for pre-clinical imaging, is not well-studied.

The purpose of this research is to observe the energy consumption of the 21.1T system [1] used for both NMR and MRI to gain a better understanding of the individual power consumption of equipment in idle and active states. This will allow us to incorporate these findings into the acquisition system so that we can turn off unnecessary equipment.

Methods

Study Design: This study aims to assess the energy consumption of the 21.1T magnet by evaluating 14 main components involved in the system operation, as shown in Table 1. The individual components, along with their voltage, current, and power requirements, are listed in the table based on information collected from the Bruker site planning guide [2].

Power Monitors: Three different types of power monitors were used to study the individual equipment and the console as a whole unit to determine which can be turned off during different experiment setups. The Cerxxian Power Monitor with IEC C14/C13 plug/socket option was used on devices rated up to 10A, while the CrocseeAC Power Monitor will be used on devices rated up to 100A. The 100A monitors require separate Current Transformers (CTs) since they will be wired into the sub-panel.

❖ Cerxxian Power Monitor

❖ CrocseeAC Power Monitor

❖ ekmmetering Split Current Transformer- rated up to 200A

The pictures of the power monitors are shown in Fig 2.

Procedure: Voltage, current, power factor, and active energy (W) will be recorded under three conditions for each of the 14 main components:

☐ **Active State:** When the component is on but not in use.

☐ **Experiment State:** During active operation in an experiment.

☐ **Idle State:** When the component is in a low-energy "rest" state.

The initial study focuses on devices like Bruker Linear Amplifiers (BLA) rated up to 10A. Further studies will be conducted after the higher-rated power monitors are wired into the sub-panel.



Figure 1. 21.1 T world's strongest MRI magnet



Figure 3a. RF amplifiers of the Avance Neo 2 Bay Console; BLA 1-4



Figure 3b. Bruker Smart Magnet Control System (BSMS) and BLA 5



Figure 3c. GREAT 60 Amplifiers



Figure 3d. 200A IECO Gradient amplifiers

Figure 3 a,b,c and d: Shows the major components of MRI system



Figure 2a. Cerxxian power monitor



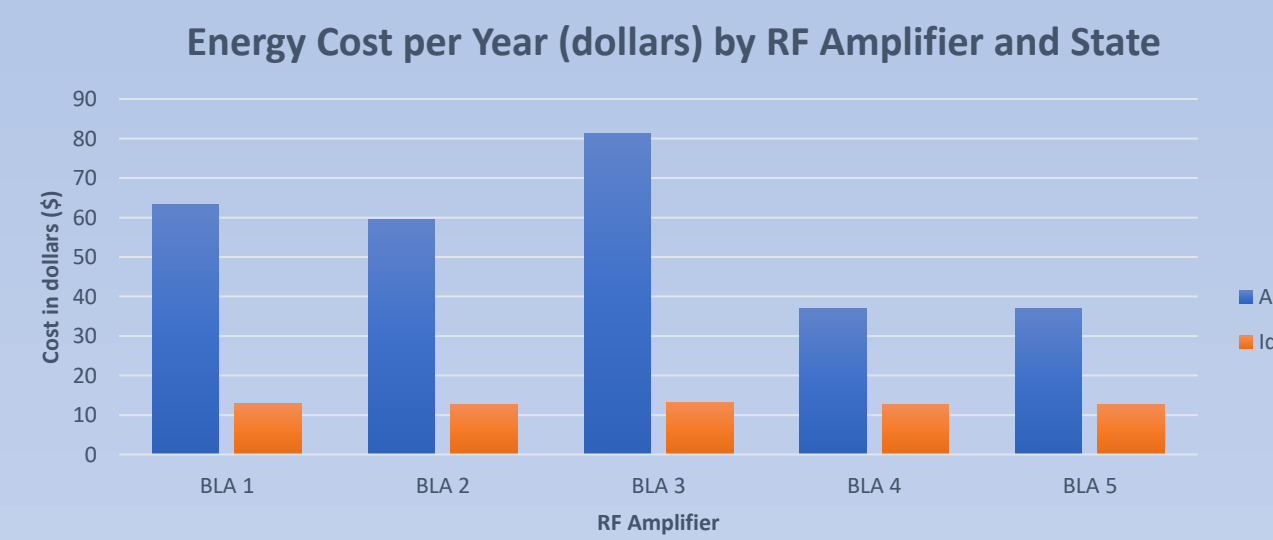
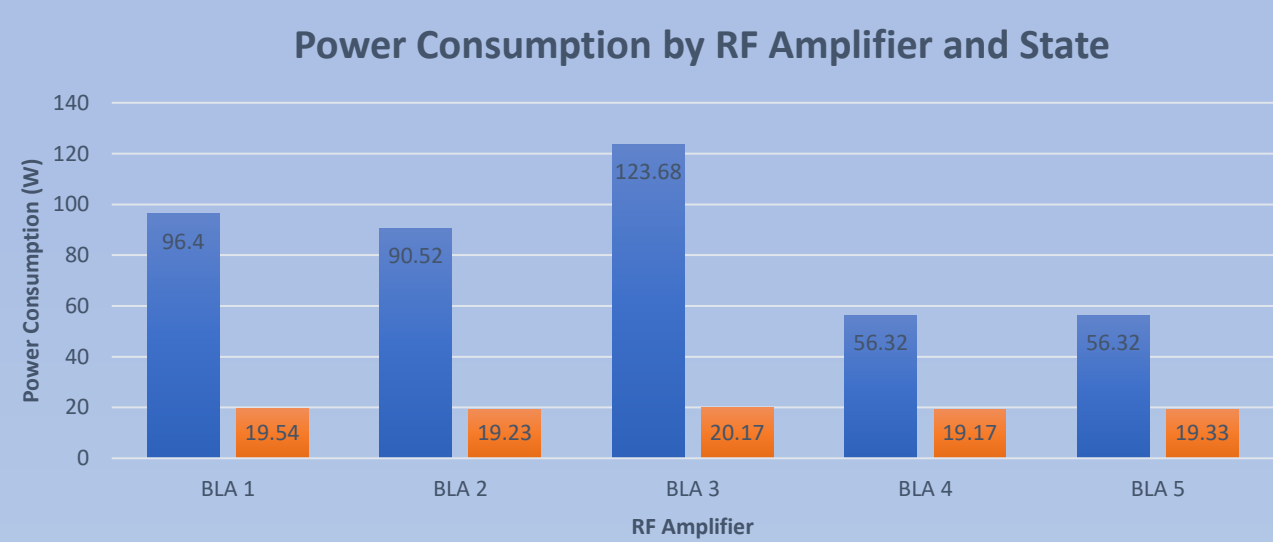
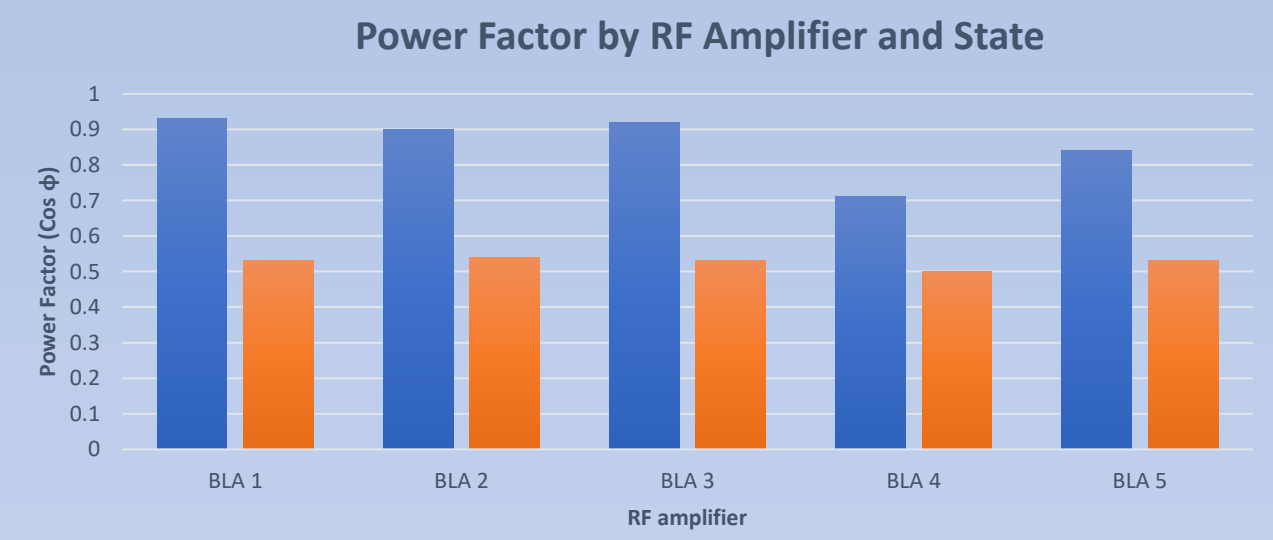
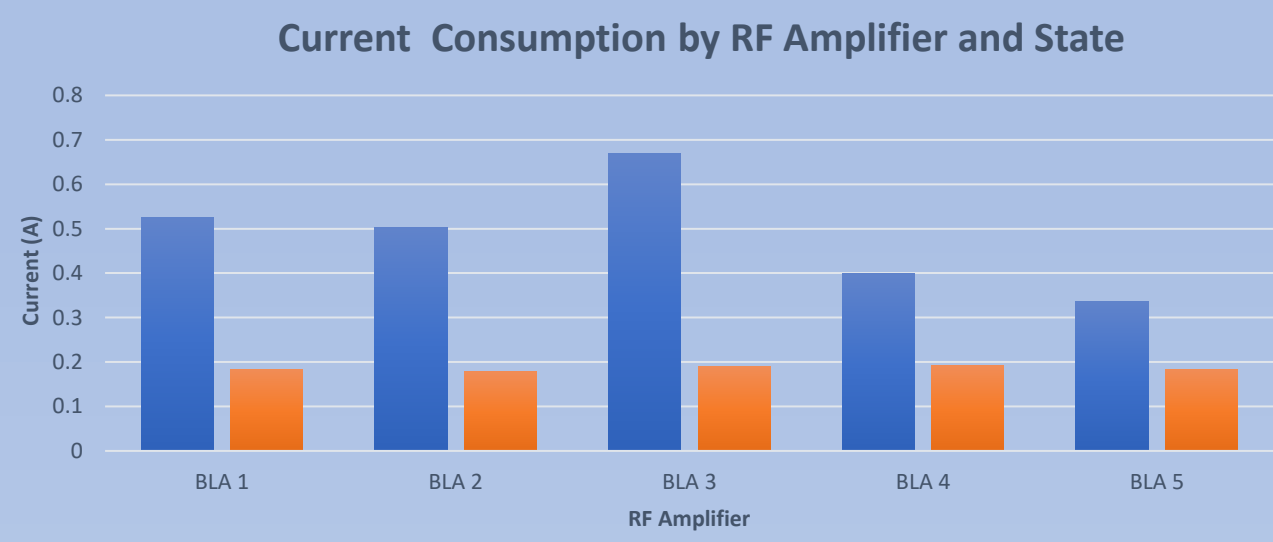
Figure 2b. CrocSee AC power monitor



Figure 2c. Ekmmetering split CT

Equipment name/Part number	Voltage	Current	Phase /Wiring	kVA	AWG sizes	Power monitor to use	CT Monitor to use
Avance Neo 2 Bay console /H176076TB including the AQS, BSMS and five different BLA RF amplifiers	208-230V	30A	1 phase / 2 wires +PE	6.90 kVA	9 AWG (6.0mm ²) (500W) (600V)	CrocSeeAC power monitor	ekmmetering split CT
Micro Imaging Diffusion SWB Driver Cabinet/HMICDIFF-04	230V	32A	1 phase / 2 wires +PE	8 kVA	9 AWG (6.0mm ²) (500W) (600V)	CrocSeeAC power monitor	ekmmetering split CT
Avance - E 1 bay HMIMAG/W156129 (Great 60) including the X, Y and Z gradient amplifiers	208-230V	30A	1 phase / 2 wires +PE	6.90 kVA	9 AWG (6.0mm ²) (500W) (600V)	CrocSeeAC power monitor	ekmmetering split CT
BCU 20 Bruker chiller	230V	5.6A	1- Phase	1.3 kVA		CERXXIAN power monitor	Not needed
SP Scientific Chiller/XR902A13	120V	9A	1-Phase	1.08 kVA			
Lyttron MRI Kodiak chiller/RC022J03FB2M413	208/230V	10A	1-Phase	2.3 kVA		CrocSeeAC power monitor	ekmmetering split CT
Host CPU-1- To run the data						CERXXIAN power monitor	Not needed
Back up CPU-2- To process the data						CERXXIAN power monitor	Not needed
Monitor 1- To visualize Paravision software						CERXXIAN power monitor	Not needed
Monitor 2- To visualize Top spin software						CERXXIAN power monitor	Not needed
Monitor 3- To monitor respiration of animals						CERXXIAN power monitor	Not needed
AV3 Gradient cabinet 400/350 (IECO Amplifier) including the XY and Z gradient amplifiers	400/480V	60A	3- Phase				

Figure 4. Table containing relevant equipment and their specifications



Results

The idle and active state measurements of the RF amplifiers shown in Charts 1,2, and 3 indicate significant increases in energy consumed by the RF amplifiers when they are left active and not put into idle state. When in active state, the amplifiers consumed an average of 65.16 watts more power and 0.3004 amps more current than in idle state. These energy consumption differences also led to a cost disparity, with active state averaging \$42.81 more than idle state over a 12-hour use period. It should be also be noted that these components are usually left running 24 hours a day, further supporting the idea that shifting the amplifiers into idle state would be beneficial in lowering both cost and energy consumed. Regarding the other components, We are still in the process of collecting complete data for my research study. This data will include the energy consumption of all equipment during different experiments. We aim to use the results to determine the most energy-efficient way of collecting data from pre-clinical MRI systems.

Conclusion

This study sheds light on the energy consumption of magnets and their components involved in solid-state NMR experiments and pre-clinical imaging, emphasizing how different operational states affect power usage. Preliminary results indicate that active states consume the most energy. Significant power savings can be achieved by switching off equipment during night hours or placing them in an idle state when not in use.

Initially, we aim to characterize the efficiency of individual equipment and later assess the overall system efficiency. This approach allows us to identify and separate the used and unused components of a typical MRI/NMR experiment. Future research should explore automated data collection, energy-saving hardware modifications, and comparisons across different spectrometer models to enhance efficiency.

Reducing NMR and MRI energy use can lower costs and benefit the environment. This study's insights can help labs use instruments more efficiently and guide manufacturers to create more sustainable designs. By improving practices and hardware, we can achieve more energy-efficient imaging.

Acknowledgements

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References

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