Development and Integration of a General-Purpose Automatic Tuning and Matching Circuit for Stretchable Coils

Folk Narongrit, Graduate Student *Member, IEEE*, Joseph V. Rispoli, *Member, IEEE*

Abstract— **Magnetic resonance imaging (MRI) plays a crucial role in advancing diagnostic capabilities in medicine. Flexible and stretchable RF coils have emerged as promising alternatives to traditional rigid coils, offering improved conformity to patient anatomy and the potential for enhanced image quality. However, these coils are sensitive to changes in shape—such as stretching, compression, or bending—which can alter their inductance and lead to shifts in resonance frequency. This shift negatively impacts the signal-to-noise ratio (SNR) and overall image fidelity. To overcome this limitation, we developed a fully non-magnetic system that can detect and retune the resonance frequency of RF coils back to the Larmor frequency. Designed for in-bore operation, the system supports frequencies up to 600 MHz and achieves tuning precision within ±0.04 MHz at 3 T. In phantom imaging experiments using a deformed coil, the system improved SNR by as much as 30%. These results highlight the potential of this approach as a foundation for future MRI systems that incorporate automatic tuning and matching, ensuring consistent performance across various coil types, anatomical geometries, and magnetic field strengths.**

***Index Terms*—RF coil, magnetic resonance imaging, resonant frequency**

I. INTRODUCTION

MAGNETIC resonance imaging (MRI) is a powerful tool in modern medical diagnostics. Conventional RF coils used in MRI are typically rigid, limiting their ability to conform to a patient's body. In contrast, stretchable and flexible coils offer better anatomical adaptability, which can lead to improved image quality and increased patient comfort. These advantages may also contribute to more accessible and cost-effective MRI systems. However, a key challenge with flexible coils is that stretching, compressing, or bending them alters their geometry and inductance, leading to shifts in resonance frequency that can degrade image quality and limit clinical use.

While frequency tuning and matching systems are well-developed in the field of antennas, particularly in sensor and wireless applications, this issue has not traditionally been a concern in MRI, as rigid coils maintain a stable inductance. The growing interest in flexible coil technologies has brought this challenge to the forefront.

Several prior studies have explored methods to minimize frequency shifts, including the use of programmable gate arrays for in-field signal processing, reflected power detection circuits, and materials such as interdigitated capacitors or liquid metals. While these approaches offer partial solutions, they are often limited in scope, tailored to specific coil designs, or reliant on ferromagnetic components like ferrite cores. This presents a significant limitation for broader implementation, especially in systems intended for use within the MRI environment.

In response, this work introduces a fully non-magnetic system capable of detecting and correcting resonance frequency shifts in stretchable coils. The system is designed to operate effectively up to 600 MHz and does not require any hardware changes to accommodate different configurations. Building upon earlier in-bore detection work, this system takes a step further by actively and dynamically compensating for frequency drift during operation.

II. PROJECT OUTCOMES

A. *Aim 1: Resonance Frequency Detection and Feasibility at MRI Larmor Frequency*

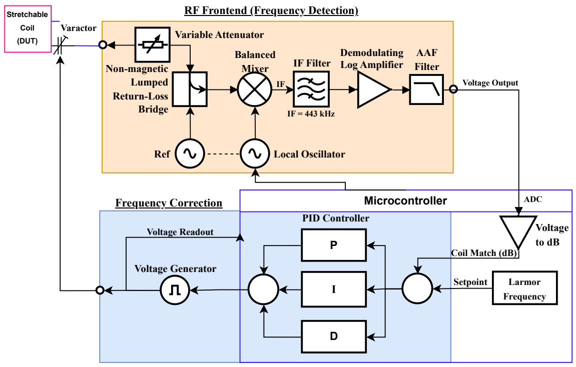

Fig. 1. Block diagram of the system

To address resonance frequency drift in stretchable MRI coils, the authors designed a non-magnetic system that detects and adjusts resonance frequency without interfering with MRI operation. A superheterodyne frequency detection architecture was implemented using a frequency synthesizer (Si5351) capable of sweeping signals up to 900 MHz, transmitted to the coil via a coaxial cable. Reflected signals were routed through a non-magnetic directional coupler composed of resistive Wheatstone-bridge components, downconverted using a double-balanced mixer (SA612), and filtered at 455 kHz using a ceramic IF bandpass filter. Signal power was measured with

Folk Narongrit is with the Elmore Family Department of Electrical and Computer Engineering and the Weldon School of Engineering, Purdue Univesrity, West Lafayette, IN 47906 USA (email narongrit@ieee.edu).

Joseph V. Rispoli is with the Department of Radiology and Medical Imaging, University of Virginia, Charlottesville, VA, USA (email jvr4a@virginia.edu).

a logarithmic amplifier (AD8310), digitized, and analyzed using a microcontroller.

The resonance frequency was determined using a golden-section search algorithm applied over a sweep range of 120–135 MHz. The coil tuning was then adjusted using a varactor diode (MACOM) controlled by a digitally adjustable power supply. The frequency correction loop was closed using a PID controller implemented on a low-power dual-core Arm Cortex-M0+ microcontroller. Simulation and co-simulation of the system using HFSS and ADS verified operation near 128 MHz (3 T), with the system achieving retuning precision up to ±0.04 MHz. Importantly, all components were non-magnetic, ensuring MRI compatibility and eliminating image artifacts.

The work in this aim has been presented and published in [2].

B. Aim 2: System Construction and Evaluation Under Coil Deformation

A stretchable 8×10 cm rectangular RF coil was constructed using tinsel copper thread on a Tricot substrate, with multilayer ceramic capacitors for matching and tuning. The coil underwent up to 30% stretch and 40% compression to evaluate resonance behavior and system performance [1]. Bench testing confirmed that the system could accurately detect and correct frequency deviations caused by mechanical deformation. Comparison with S11 measurements from a network analyzer showed that the system successfully restored resonance to the Larmor frequency with an error margin of ±0.04 MHz.

To evaluate the system's stability, the corrected resonance frequency was maintained for 15 minutes using constant varactor bias, showing minimal drift (±0.2 MHz by network analyzer and ±0.35 MHz by the system). This confirmed the system's robustness and its suitability for practical scan durations.

The work in aim 2 has been presented and published in [3].

C. Aim 3: Integration of Feedback Control and MRI Validation

The automatic retuning system was integrated with the stretchable coil and tested inside a clinical MRI environment. The full system—mounted on a custom PCB—was interfaced with the coil via coaxial and twisted-pair cables and tested in phantom imaging. A cylindrical phantom was scanned before and after frequency correction. The system performed a single tuning operation before imaging, after which the corrected resonance frequency was held constant.

The results demonstrated a substantial SNR improvement from 311.1 (uncorrected) to over 400 after tuning. This SNR gain (approximately 30%) persisted in scans taken immediately, and at 5- and 10-minutes post-correction, confirming the system's effectiveness and temporal stability. The system's non-magnetic design allowed in-bore operation without heating issues or image artifacts, consistent with IEC 60601-2-33:2022 safety standards.

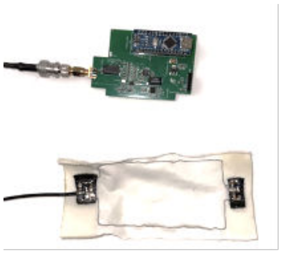

Fig. 2. Experimental setup, with the stretchable coil connected to the system using a coaxial cable.

III. FUTURE CAREER PLAN

My short- and long-term career goals are rooted in academia, a path I have always been passionate about. I plan to begin as a postdoctoral researcher, with the aim of transitioning into a tenure-track faculty position in electrical engineering, biomedical engineering, or a related field focused on MRI hardware. The MTT-S Fellowship has played a pivotal role in shaping this direction. The support and recognition from the program have reinforced my commitment to continuing work on this area, especially as the promising initial results suggest a pathway toward developing a universal receive coil system for MRI.

IV. IMS 2024 IMPRESSIONS

I truly enjoyed my time at IMS 2024 in Washington, D.C. and felt incredibly fortunate to be part of the vibrant and welcoming MTT-S community. The conference provided a unique opportunity to connect with researchers from around the world and gain a broader perspective on the current state-of-the-art in microwave technologies. One of the most memorable aspects of the experience was meeting and speaking with leading figures in the field, whose insights helped shape my thinking about future research directions. Attending IMS also played a key role in solidifying my decision to pursue a career in academia. Receiving the MTT-S Fellowship and being recognized among such a talented group of researchers was a humbling and motivating experience that has had a lasting impact on my academic path.

REFERENCES

[1] F. W. Narongrit, T. V. Ramesh, and J. V. Rispoli, "Stretching the limits of MRI—stretchable and modular coil array using conductive thread technology," IEEE Access, vol. 12, pp. 89613–89620, 2024.

[2] F. W. Narongrit, T. V. Ramesh, and J. V. Rispoli, "Resonance frequency detection system for MRI RF coils," presented at the IEEE-EMBS Conference on Biomedical Engineering and Sciences, Penang, 2024.

[3] F. W. Narongrit, T. V. Ramesh, and J. V. Rispoli, "Resonance Frequency Retuning System for Flexible MRI Coils," presented at IEEE IMS, San Francisco, 2025.