# Active Feedback-Enhanced MRI: Hardware Development and Applicatiosn to Early Tumor Detection

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## Theory and Methods

Feedback fields such as radiation damping (RD) and the distant dipolar field have demonstrated their potential in contrast enhancement and highlighting structures not visible in conventional imaging [1-3]. In this conceptually new approach, contrast enhancement is achieved by manipulating the intrinsic spin dynamics in the presence of nonlinear feedback interactions. Evolution under the feedback fields allows the spins themselves to play an active role in determining and differentiating their subsequent evolution, thereby improving the distinction between regions with different MR properties. Nevertheless, for most MR spectrometers/scanners, the sensitivity and quality factor of the RF receiver coil is not high enough to induce a strong RD field. Utilizing an external electronic device can significantly enhance the RD feedback field.

In this work, we demonstrate an active RF feedback loop (Fig. 1) to amplify and control the RD feedback field. To integrate this external feedback device with conventional MR imager/scanners, we can create a quasi-real time feedback signal. In addition, the phase and gain of the feedback field is also controllable, which allows for the design of new imaging pulse sequences.

## Results

To validate the efficacy of active RF feedback, tumor detection and characterization in *in vivo* mice was investigated. The mice were injected subcutaneously with human lung cell line with green fluorescent protein (GFP) expression, which can be easily tracking by optical imaging. The sample was first excited by a single–shot hard pulse, followed by evolution under active RD feedback. The sample was then imaged by conventional spin-echo imaging. To eliminate the artifacts induced by background field inhomogeneity, a small flip-angle hard pulse ($5^o$) was applied, and the phase of feedback field was tuned to be 40~$60^o$ out of phase. The small excitation angle provided more uniform initial conditions, and the out-of-phase feedback field may act like a self-refocusing sinc pulse to reduce the artifacts induced by background field inhomogeneity.

The resulting active RD feedback-enhanced image showed strong contrast and highlighted boundaries in an early stage tumor [Fig. 2(b)]. These features were barely observable in the corresponding conventional proton density, T1-weighted, T2-weighted, and T2*-weighted images [Figs. 2(a), (c)-(e), respectively]. Moreover, the tumor size observed in the active RD feedback-enhanced image was consistent with that measured by the histology [Fig. 2(f)]. Figure 3 demonstrates another advantage of active RD feedback-enhanced images. In comparison with the optical image [Fig. 3(a)], active RD feedback-enhanced image can clearly indicate more detailed tumor structure [Fig. 3(b)] which cannot be distinguished by conventional image, such as T2-weighted image [Fig. 3(c)].

## Discussion and Conclusion

In summary, differential excitation under the feedback field distinguishes tissues and enhances contrast at the tissue boundaries, especially for lesions such as tumors. The development of an active feedback circuit to amplify the RD field thus enables improved differentiation of neighboring normal and abnormal tissues at low fields using conventional probes/receiver coils.

## References

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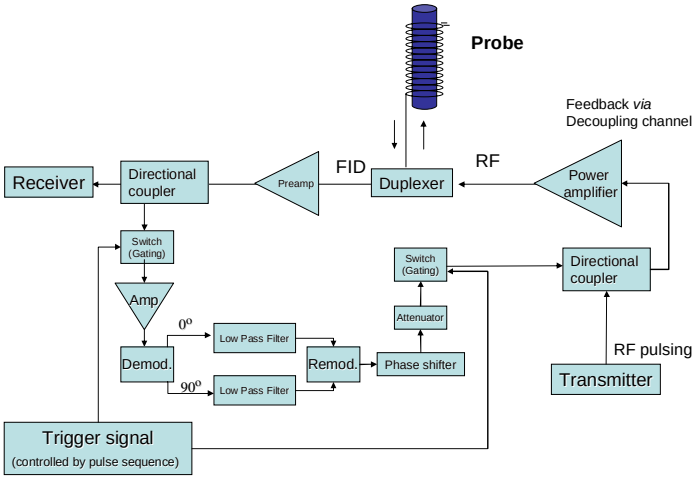


**Fig. 1.** Block diagram of active radiation damping feedback circuit.

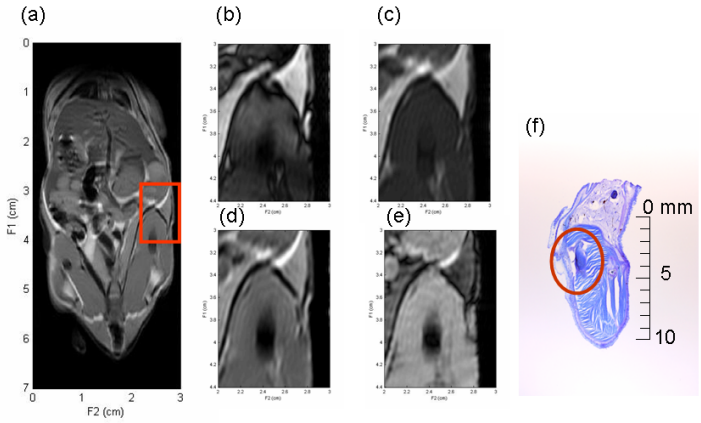


**Fig. 2.** Tumor of mice in vivo. (a) Proton density image. (b) Active feedback-enhanced image. (c) $T_1$-weighted image (d) $T_2$-weighted image. (d) $T_2^*$-weighted image. (f) Histology.

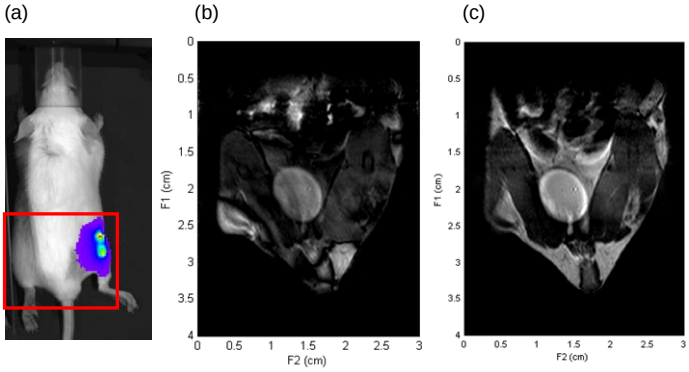


**Fig. 3.** Tumor of mice in vivo. (a) GFP expressing optical image. (b) Active feedback-enhanced image. (c) T2-weighted image.