Structural-Acoustic Analysis, Identification and Control of a 4T MRI Scanner

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Introduction

High-field, high-speed imaging techniques, such as echo planer imaging (EPI) used at 3T or 4T, emit acoustic noise typically in the range of 120-130 dB [1]. This noise is seriously annoying fro both patients and healthcare workers. It is also a potential health issue, particularly in terms of its effect on hearing. In this study, we conducted a series of experiments to identify the major acoustic noise sources and their relative contributions. The approach involved quantifying a set of impulse response functions [2-3] that can be applied to synthesize the actual operating response for any gradient excitation pulses. The results are intended to guide the development of a suitable active noise control (ANC) system. In addition, a preliminary simulation study is also presented to demonstrate the achievable noise reduction at the principal harmonic.

Method and Results

Acoustic noise measurement was conducted with a 4T Varian UnityINOVA whole-body MRI scanner operated using an EPI pulse sequence. The sound pressure data was acquired using a set of special-purpose, omni-directional non-ferrous microphones placed at positions equivalent to a patient's ear and mouth guided by a humanoid dummy. The sound pressure signals and gradient excitation pulse waveforms were acquired simultaneously with a multi-channel digital data recorder and processed using a high-speed computer. Two types of gradient excitations were applied: (a) actual operating pulses (i.e. EPI scan) and (b) artificial impulse excitations (i.e. a single short-duration triangular pulse).

The measurements were also analyzed in detail to determine the sources of the major response peaks. Figure 1 illustrates the origins of the harmonics (1, 2...), non-harmonics (0) and broadband responses for the X, Y and Z gradient excitations shown in Figs 1a, 1b and 1c, respectively, for a typical measurement. Furthermore, using the transfer functions obtained from the impulse excitation tests, we were able to synthesize the operating noise levels accurately for any gradient excitation. Figure 2 shows the predicted left ear acoustic spectrum as compared to the measured response along with the Y-gradient excitation (frequency-encoding) and transfer functions used in the synthesis. The agreement between the measured and the estimated results demonstrates the linearity of the system.

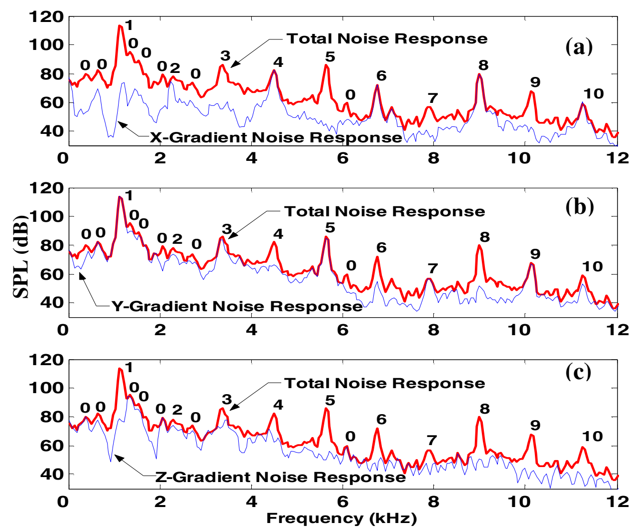

Fig. 1 - Acoustic noise source identification: (a) X-gradient; (b) Y-gradient; (c) Z-gradient.

Conclusion

According to these findings, it is conceivable that a suitable active noise control system can be developed for this MRI system. Our target is to suppress the MRI sound field in the vicinity of the ear and mouth. In our preliminary simulation (shown in Fig. 3), we estimate an achievable target of about 20dB reduction in the fundamental frequency of the acoustic noise response. Our results revealed that the frequency-encoding gradient, which produces both odd harmonic and non-harmonic responses, is the most dominant amongst the three gradients' contributions. By utilizing a set of impulse response functions, the acoustic noise responses can be accurately synthesized for any operating condition. A preliminary active noise control simulation study suggests the potential of suppressing response peaks by about 20dB for the fundamental frequency alone. Further studies are in-progress to develop a feasible active control system.

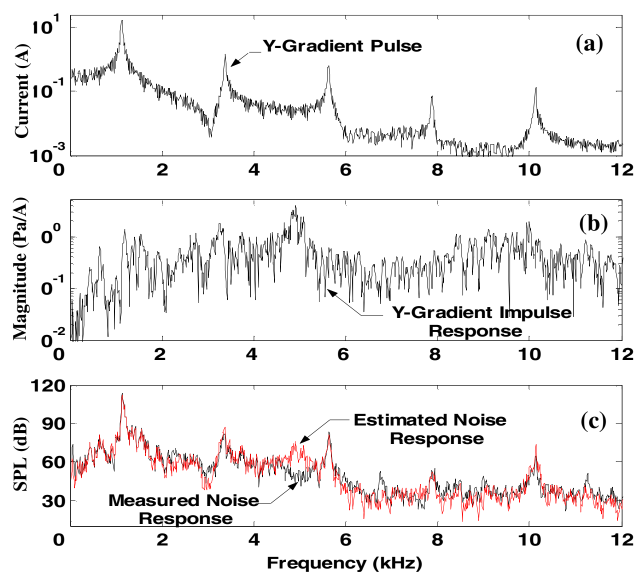

Fig. 2 - Measured and predicted acoustic noise response related to the Y-gradient input.

References

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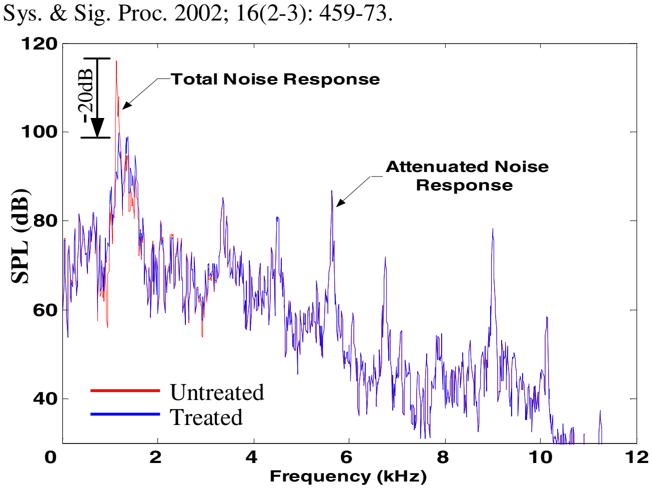

Fig. 3 - Active noise control simulation targeting the peak response of the fundamental frequency.