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Variable Gain Amplifier for MPS

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Abstract

The magnetic response of superparamagnetic iron oxide nanoparticles (SPIONs) varies significantly during nucleation and growth, requiring adaptive signal conditioning to avoid saturation and maintain sensitivity. This work presents the design and experimental characterization of a low-noise variable gain amplifier (VGA) based on the AD603 for this application. The VGA offers a pin-selectable gain range from −10 dB to +30 dB, enabling high gain at early synthesis stages and controlled attenuation at later stages. Performance was evaluated in terms of transient response, gain, phase behavior, and noise characteristics over a frequency range of 1 kHz to 1 MHz. Measurements demonstrate stable gain, limited phase variation, and improved noise performance through parallel amplifier configurations, indicating suitability for low-noise, high-dynamic-range SPIONs measurement systems such as MPS/MPI devices.

I. Introduction

During the synthesis of superparamagnetic iron oxide nanoparticles (SPIONs), particularly in the initial stages of nucleation and growth, the magnetic response of the particles is weak. As the synthesis progresses and the SPIONs grow, their magnetic response increases accordingly [1]. Therefore, it is necessary to match the dynamic range of analog to digital convertor (ADC). This variation in signal amplitude may lead to saturation of subsequent modules in the signal chain, making signal attenuation necessary at later stages of growth. Therefore, a system capable of providing high gain during initialization and controlled attenuation during the final stages is required. To address this need, a variable gain amplifier (VGA) based on the AD603 (Analog Devices, USA) was designed. The AD603 is a low-noise, voltage-controlled amplifier with pin-selectable gains ranging from −10 dB to +30 dB and a bandwidth of 9 MHz. It features an input-referred noise density of 1.3 nV/$\sqrt{\text{Hz}}$, supports load impedances as low as 100 Ω, and exhibits a total harmonic distortion of −60 dBc for a ±1 V sinusoidal output at 10 MHz.

II. Materials and Methods

A variable gain amplifier (VGA) based on the AD603 (Analog Devices, USA) was designed (Figure 1). The transient output voltage was measured using an oscilloscope (HDO6104-MS, Teledyne LeCroy, USA). The input signal was generated using a function generator producing a 25 kHz sinusoidal waveform with an amplitude of 170 mV. Gain and frequency response measurements were performed using a network analyzer (E5061B, Keysight Technologies, USA). For noise characterization, the VGA output was directly connected to a spectrum analyzer (EXA-N9010A, Keysight, USA). The input-referred voltage noise was measured using a 50 Ω termination at the input of

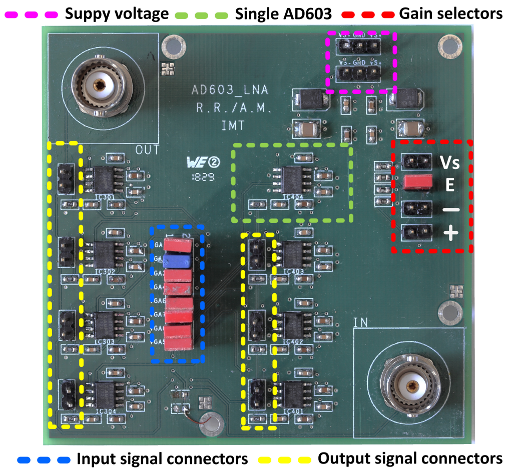

Figure 1: Manufactured PCB of the prototyped VGA with all eight AD603 parallel at maximum gain.

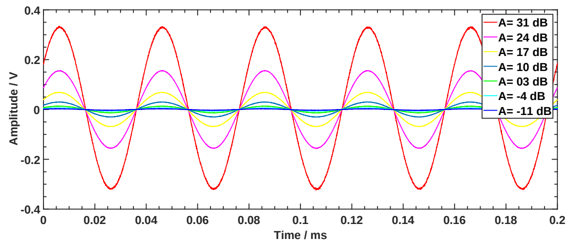

Figure 2: The transient response of the designed VGA based on AD603. The input signal for measuring the transient response is 10 mV.

the VGA, with the amplifier configured at its maximum gain of 31 dB. All measurements were conducted over a frequency range of 1 kHz to 1 MHz using 100 averages. The resolution bandwidth (RBW) and video bandwidth (VBW) were set to 10 Hz and 30 Hz, respectively.

III. Results

The measured transient response for gain settings ranging from −11 dB to 31 dB, along with the frequency and phase responses of the designed PCB at maximum gain, is shown in Figure 2. The maximum measured system gain was 29.37 dB, which is slightly lower than the datasheet specification, with a variation of only 0.1%, indicating high stability. The phase shift up to 1 MHz was approximately 5° (1.4%), which can be readily compensated using the system transfer function.

Noise was evaluated according to section II, the input-referred noise as a function of frequency is shown in Figure 4 for a single AD603 as well as for configurations with two to eight AD603 amplifiers connected in parallel. Due to the parallelization the configuration with eight AD603 shows the best noise characteristics.

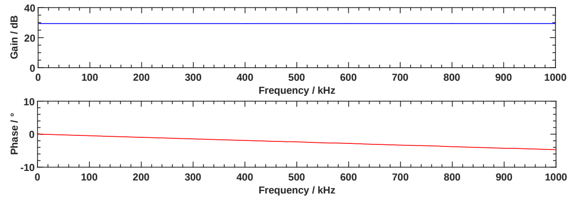

Figure 3: The gain and phase response of the designed VGA based on AD603.

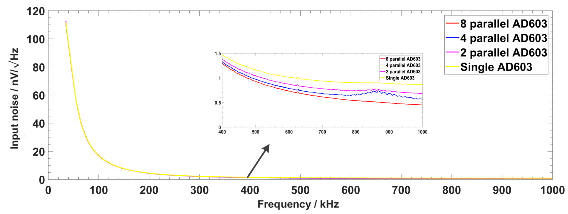

Figure 4: Input noise calculated from the measured data from the signal analyzer with 50 Ω resistance.

IV. Conclusion

A variable gain amplifier based on the AD603 was designed and characterized for signal conditioning during SPION synthesis. The VGA demonstrates stable gain and phase behavior over the measured frequency range, while amplifier parallelization improves noise performance. The proposed design is suitable for low-noise, high-dynamic-range signal acquisition in SPION-based systems.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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