ARMY RESEARCH LABORATORY

High-impedance Buffer Amplifier for Micro-electromechanical System (MEMS) Resonator Measurements

by Brianna Murphy and Roger Kaul

ARL-TN-0412 **September 2010**

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14. ABSTRACT

The electrical performance of micro-electromechanical system (MEMS) resonators built at the U.S. Army Research Laboratory (ARL) requires measurement techniques that do not overstress the devices. As a result, we need a high-impedance amplifier that operates over an extended frequency range suitable for use ahead of a 50-ohm vector network analyzer (VNA). The prototype amplifier "buffers" the resonator from the VNA. This amplifier was designed, fabricated, and tested during a four-week period. It demonstrates that future designs using operational amplifiers with wider frequency ranges will be suitable for this application.

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Amplifier, MEMS

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1. Introduction

The goal of this work is to design, fabricate, and test an operational amplifier to have high input impedance (appreciably greater than 50 ohms) and low output impedance. This type of circuit is desirable because the output of the circuit will interface and be measured with a vector network analyzer (VNA). Typically the input impedance of a network analyzer is 50 ohms. With a low output impedance from the operational amplifier circuit, optimum efficiency and minimum reflection will be achieved when interfaced with the VNA. In addition the operational amplifier circuit will be able to drive the network analyzer with the proper amount of current needed for measurement. The gain of the operational amplifier is to be in close proximity to unity, have a wide-bandwidth, and be built with the available parts from the U.S. Army Research Laboratory's (ARL) bench stock. The circuit is a variation on the classic inverting-op amp configuration and the resistors were chosen as 1 kΩ and 1 kΩ, in order to ensure a gain of –1 (hence the 180° phase shift).

Analog Devices AD817 was selected for this prototype buffer amplifier. The output impedance of the currently available micro-electromechanical system (MEMS) resonators is high compared to the 50-ohm input impedance of the VNA used to measure their performance. As a result of the 50-ohm load presented to the resonator, the output signal level of the resonator is low and the dynamic range of the measurement is limited. It is possible to remove the effect of the 50-ohm load using available software, but this is an extra step in the data analysis and it does not allow us to see the full dynamic range of the resonators.

Commercial high-impedance probes are available, but these units are designed for probing circuits and cannot be integrated into a circuit incorporating both the resonator and any impedance matching circuitry. Hence, being able to design and fabricate high-impedance buffer amplifiers within ARL is desirable for advancing our MEMS resonator activities. Future designs will build on this experience and utilize higher-frequency circuits.

2. Circuit Design

Figure 1 shows the schematic for the designed circuit. Point A is where the input impedance is measured, and Point B is where the output impedance is measured. The four bias capacitors at ports 4 and 7 are used to block noise from the DC 12-V supply and ensure stability. The source V1 will be replaced by the network analyzer in testing and will be eventually replaced by the MEMS resonator when it goes into use.

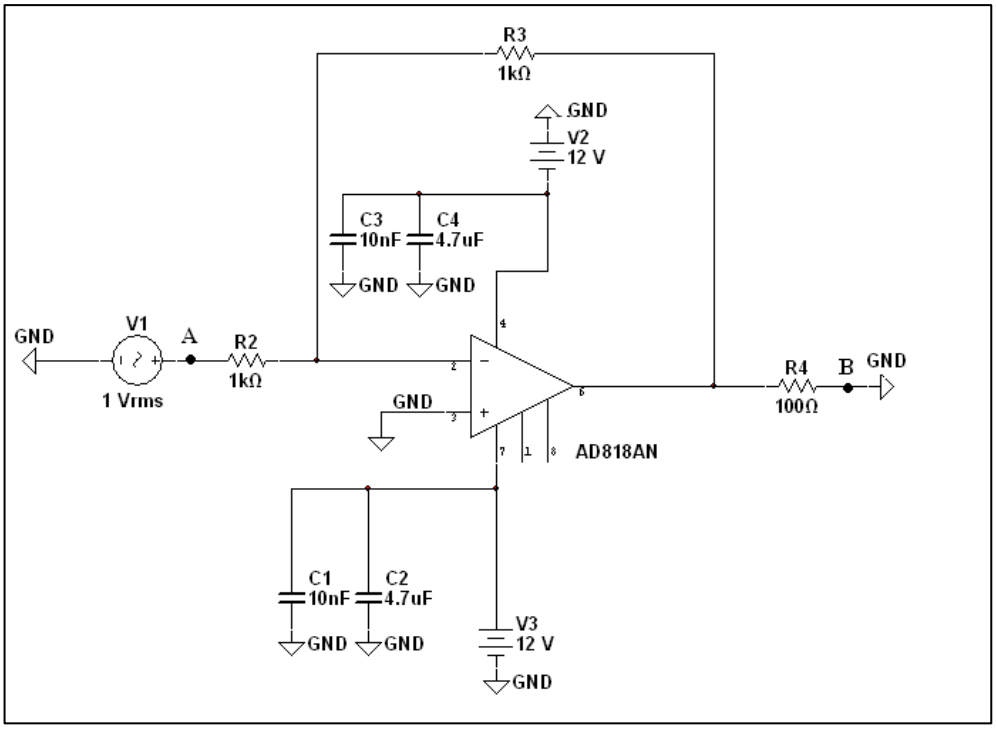
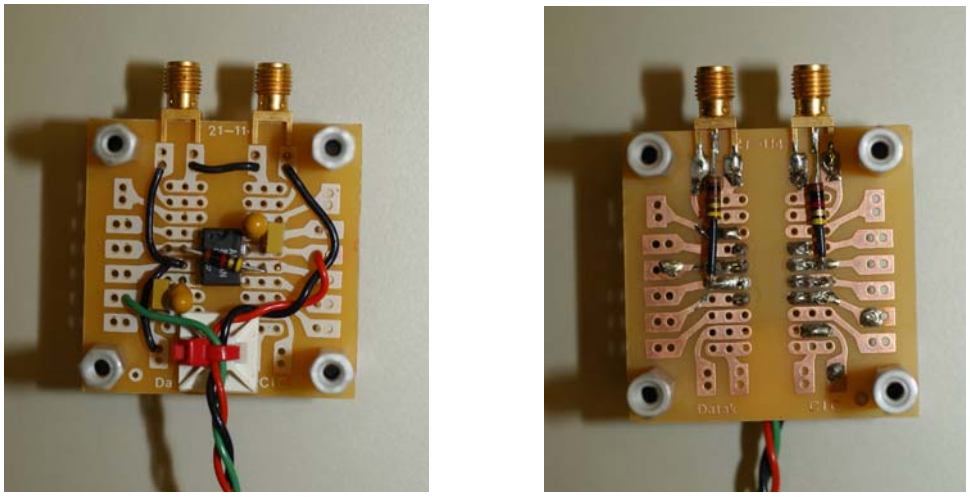


Figure 1. Circuit schematic of the operational amplifier during simulation.

Figure 2 shows the fabrication of the circuit schematic in figure 1. The black wires represent ground wires, the red wire represents positive voltage, and the green wire represents negative voltage. In figure 2a, one can see the AD817 operational amplifier in the center, the two sets of capacitors linked to port 4 and port 7, as well as the 1-kΩ resistor that crosses from pin 2 to pin 6. In figure 2b, on the left, one can see the 100-Ω resistor linked from pin 6 to the output and, on the right, one can see the 1-kΩ resistor linked from pin 2 to the input.



(a) (b)

Figure 2. (a) Fabricated circuit (top view) and (b) fabricated circuit (bottom view).

3. Simulation

A series of simulations were performed using the AD818 operational amplifier rather than the AD817, which was immediately available in ARL bench stock. The free ADSim simulation program was used, which is distributed by National Instruments and incorporates Analog Devices SPICE models. Unfortunately, because the AD817 model was not built into the ADSim program and it was not possible to add the SPICE model to the free program, direct comparisons of the simulated and measured results were not possible. For this reason, the simulated results are not included in this technical note.

However, the simulations did confirm the general results shown in section 4. The full datasheet for the AD817 is available at http://www.analog.com/static/imported-files/Data_Sheets/AD817.pdf. The first page of the datasheet, which lists the key features of this device, is included in the appendix. Note: The device sells for less than USD $5.00.

4. Measurements

The measurements were taken by connecting the circuit to a Rhode and Schwarz ZVB8 VNA. Figure 3a shows the phase versus frequency. Figure 3b shows the linear magnitude versus frequency. The S21 parameter indicates that the circuit is inductively loaded with an average magnitude of about 400. The phase range is about 180 to 45 over the frequency range from 0.3 to 50 MHz. The linear magnitude range is about 600 to 200 over the frequency range corresponding to a gain of –4.4 to –14 dB.

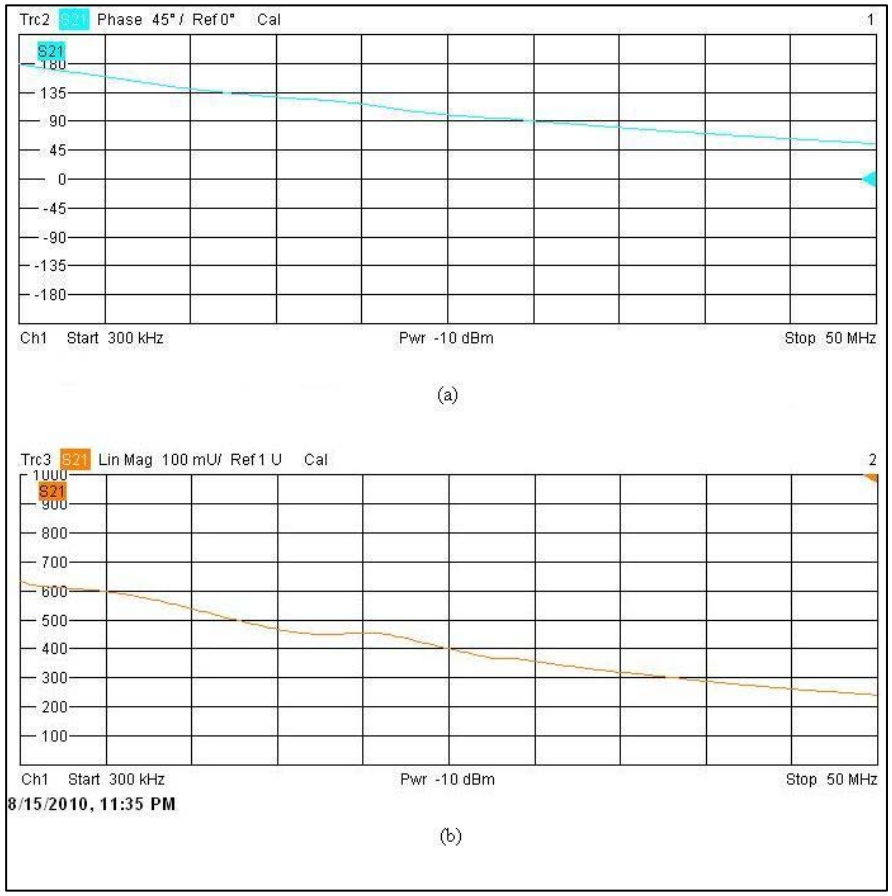


Figure 3. S21 (a) phase and (b) magnitude.

Figure 4 shows the input impedance of the circuit. This graph has a parabolic type curve and peaks around 25.15 MHz.

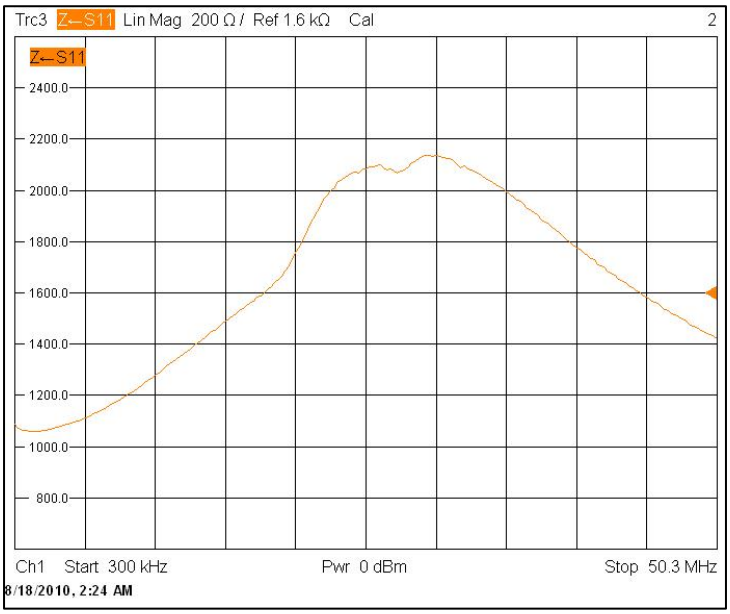


Figure 4. Input impedance.

Figure 5 shows the output impedance of the circuit. As the frequency goes higher, the output impedance, Z22, increases.

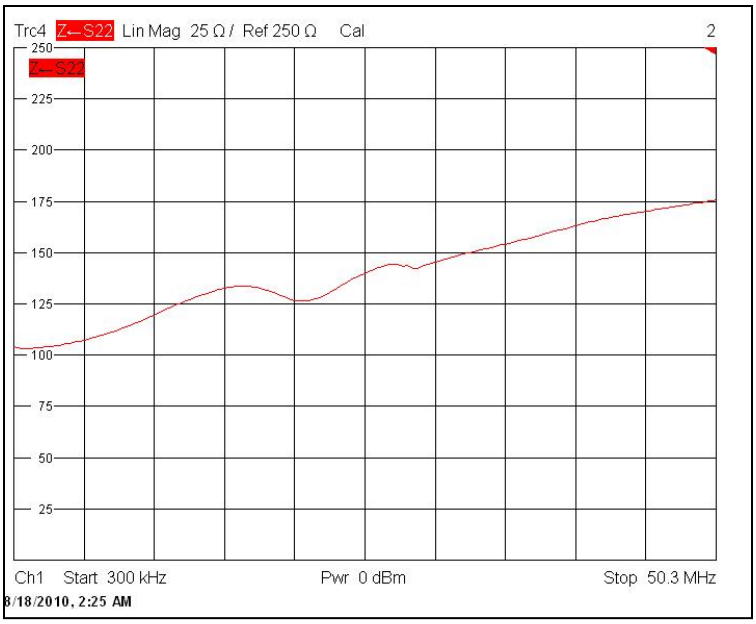


Figure 5. Output impedance.

5. Conclusion

In our research, we achieved an input impedance in excess of 1000 ohms and an output impedance of less than 200 ohms (as seen by the data). These results will provide the necessary parameters to provide the network analyzer the proper amount of current to operate successfully, without loading the output of the MEMS resonators. The frequency-dependent effects of the buffer amplifier will be included in the calibration procedure for the MEMS resonator test setup and thus will not appear in the MEMS device's measured characteristics.

Appendix. Specifications for Operation Amplifier Used in Fabricated Circuit

ANALOG DEVICES

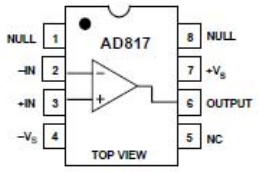
High Speed, Low Power Wide Supply Range Amplifier

AD817

FEATURES
Low Cost
High Speed
50 MHz Unity Gain Bandwidth
350 V/μs Slew Rate
45 ns Settling Time to 0.1% (10 V Step)
Flexible Power Supply
Specified for Single (+5 V) and Dual (±5 V to ±15 V) Power Supplies
Low Power: 7.5 mA max Supply Current
High Output Drive Capability
Drives Unlimited Capacitive Load
50 mA Minimum Output Current
Excellent Video Performance
70 MHz 0.1 dB Bandwidth (Gain = +1)
0.04% & 0.08° Differential Gain & Phase Errors @ 3.58 MHz
Available in 8-Pin SOIC and 8-Pin Plastic Mini-DIP

CONNECTION DIAGRAM

8-Pin Plastic Mini-DIP (N) and SOIC (R) Packages



NC = NO CONNECT

PRODUCT DESCRIPTION

The AD817 is a low cost, low power, single/dual supply, high speed op amp which is ideally suited for a broad spectrum of signal conditioning and data acquisition applications. This breakthrough product also features high output current drive capability and the ability to drive an unlimited capacitive load while still maintaining excellent signal integrity.

The 50 MHz unity gain bandwidth, 350 V/μs slew rate and settling time of 45 ns (0.1%) make possible the processing of high speed signals common to video and imaging systems. Furthermore, professional video performance is attained by offering differential gain & phase errors of 0.04% & 0.08° @ 3.58 MHz and 0.1 dB flatness to 70 MHz (gain = +1).

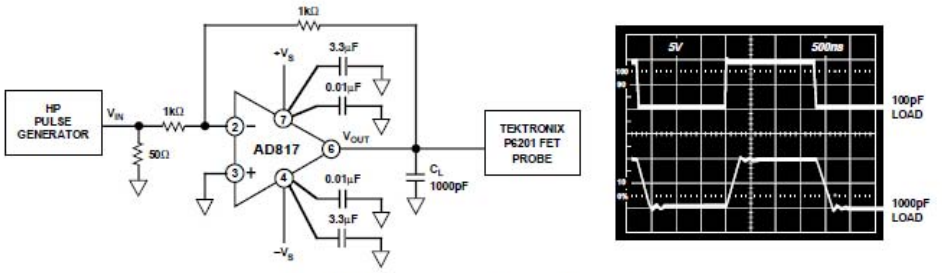
The AD817 is fully specified for operation with a single +5 V power supply and with dual supplies from ±5 V to ±15 V. This power supply flexibility, coupled with a very low supply current of 7.5 mA and excellent ac characteristics under all power supply conditions, make the AD817 the ideal choice for many demanding yet power sensitive applications.

In applications such as ADC buffers and line drivers the AD817 simplifies the design task with its unique combination of a 50 mA minimum output current and the ability to drive unlimited capacitive loads.

The AD817 is available in 8-pin plastic mini-DIP and SOIC packages.

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
AD817AN	–40°C to +85°C	8-Pin Plastic DIP	N-8
AD817AR	–40°C to +85°C	8-Pin Plastic SOIC	R-8



AD817 Driving a Large Capacitive Load

REV. B

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Tel: 617/329-4700 Fax: 617/326-8703

Figure A-1. Page 1 of the AD817 datasheet.

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