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**

NOTICES

Disclaimers

Army Research Laboratory
Adelphi, MD 20783-1197

ARL-TN-0412 **September 2010**

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

Brianna Murphy and Roger Kaul
Sensors and Electron Devices Directorate, ARL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2010	Final	

4. TITLE AND SUBTITLE
High-impedance Buffer Amplifier for MEMS Resonator Measurements

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Brianna Murphy and Roger Kaul

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: RDRL-SER-E
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TN-0412

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

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.

15. SUBJECT TERMS
Amplifier, MEMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Thomas Farmer
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (*Include area code*)
Unclassified	Unclassified	Unclassified	UU	16	(301) 394-0487

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures **iv**

Acknowledgement **v**

1. Introduction **1**

2. Circuit Design **1**

3. Simulation **3**

4. Measurements **3**

5. Conclusion **6**

Appendix. Specifications for Operation Amplifier Used in Fabricated Circuit **7**

Distribution List **8**

List of Figures

Figure 1. Circuit schematic of the operational amplifier during simulation. 2
Figure 2. (a) Fabricated circuit (top view) and (b) fabricated circuit (bottom view).......................2
Figure 3. S21 (a) phase and (b) magnitude. 4
Figure 4. Input impedance. 5
Figure 5. Output impedance..5
Figure A-1. Page 1 of the AD817 datasheet. 7

Acknowledgment

We wish to thank Mr. Arthur Harrison (RDRL-SER-M) for his helpful information about operational amplifiers and help with fabricating the prototype circuit. We would also like to thank Thomas Farmer for his help with the work itself and the completion of this technical note.

INTENTIONALLY LEFT BLANK.

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.

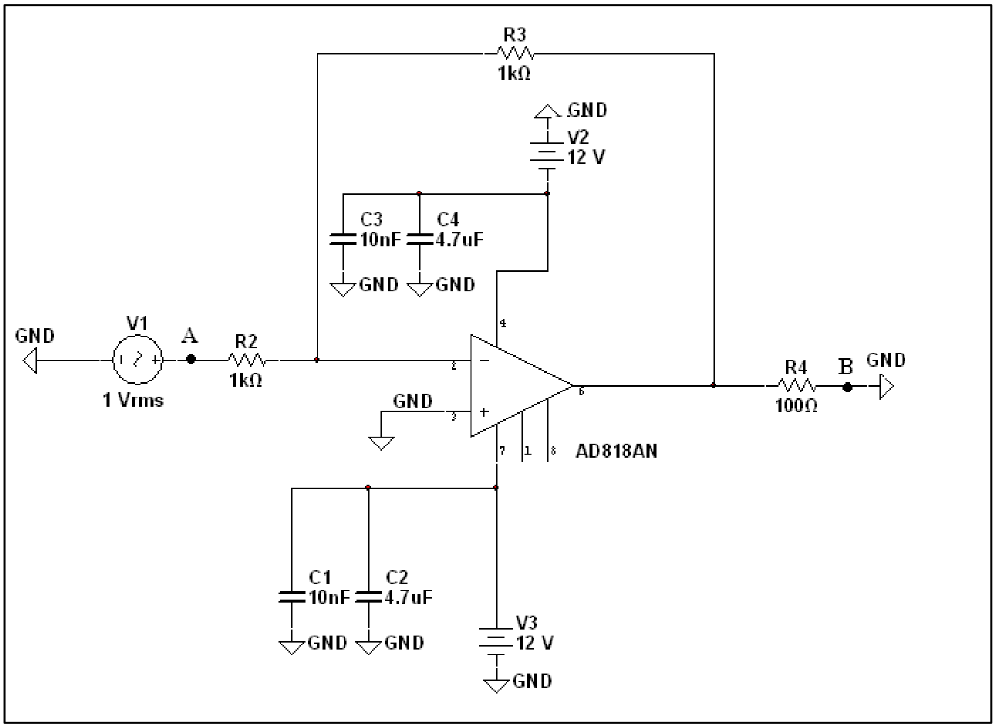
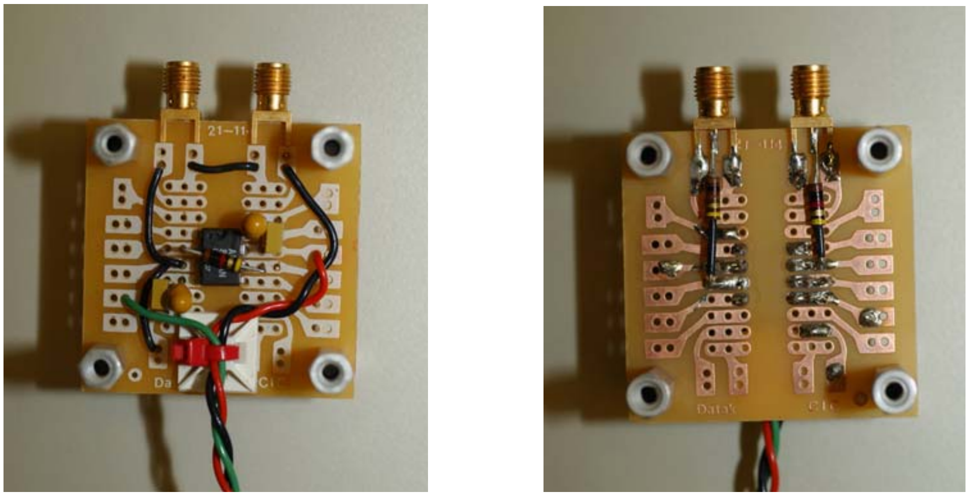


Figure 1. Circuit schematic of the operational amplifier during simulation.

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.

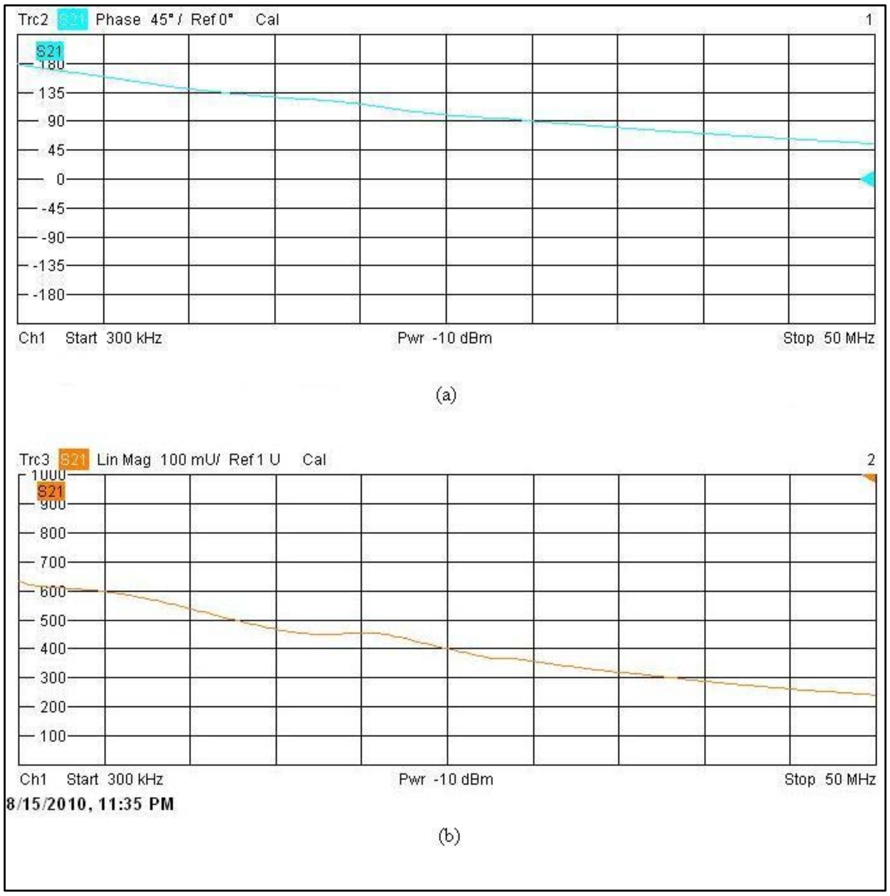


Figure 3. S21 (a) phase and (b) magnitude.

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

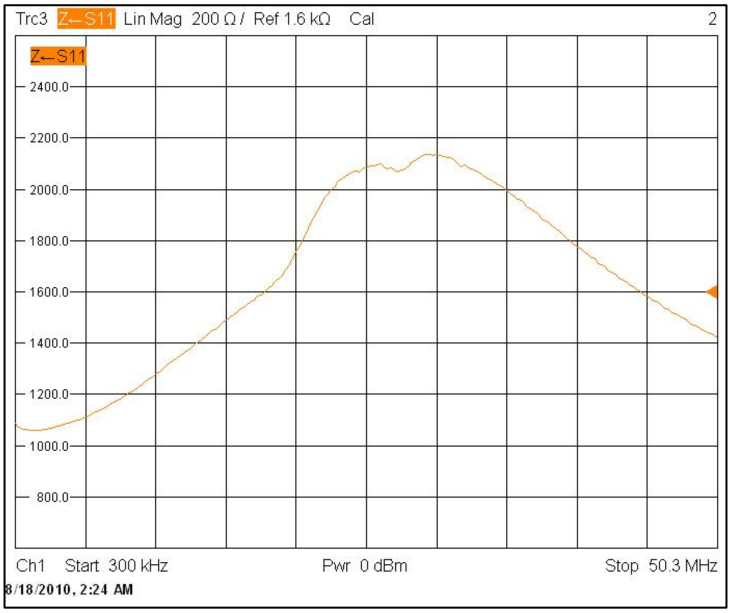


Figure 4. Input impedance.

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

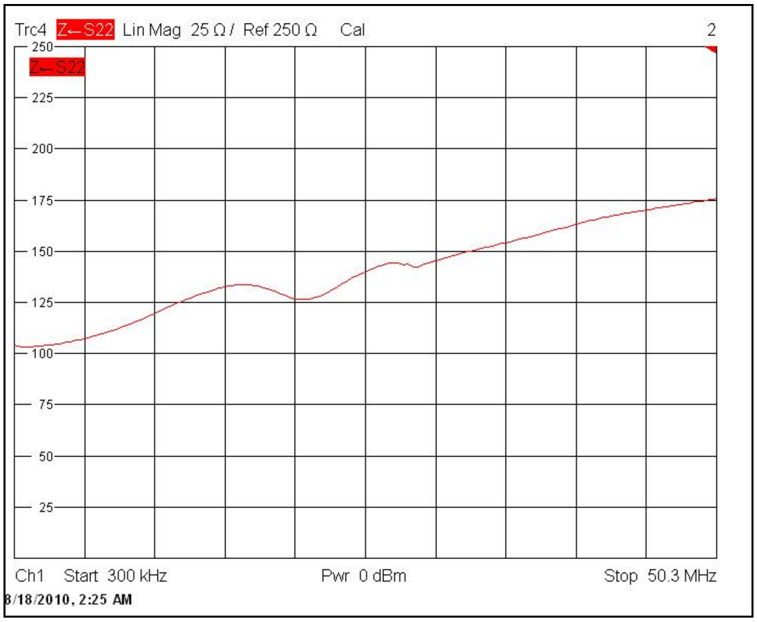


Figure 5. Output impedance.

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

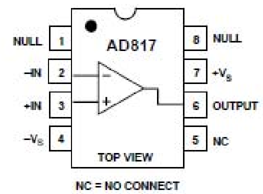
PRODUCT DESCRIPTION

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).

CONNECTION DIAGRAM

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



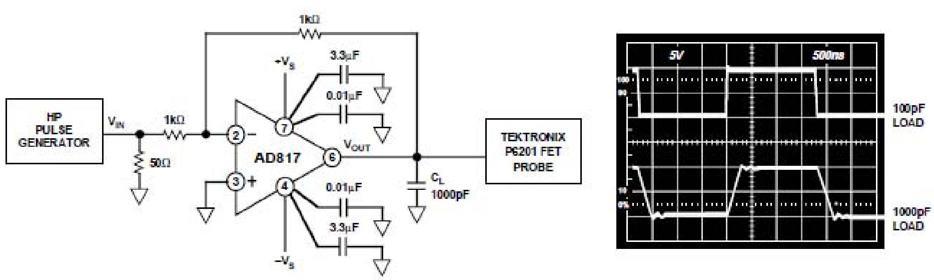
The AD817 is fully specified for operation with a single +5 V power supply and with dual supplies from ±5 V to ±15 V. This power supply flexibility, coupled with a very low supply current of 7.5 mA and excellent ac characteristics under all power supply conditions, make the AD817 the ideal choice for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

One Technology Way, P.O. Box 9106, Norwood. MA 02062-9106, U.S.A.
Tel: 617/329-4700 Fax: 617/326-8703

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

No. of Copies	Organization
1 (PDF ONLY)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FORT BELVOIR VA 22060-6218
1	DIRECTOR US ARMY RESEARCH LAB IMNE ALC HRR 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB RDRL CIM L 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB RDRL CIM P 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	UNIVERSITY OF MARYLAND DEPT OF ELECTRICAL & COMPUTER ENGINEERING MR. STEVE NORTON 2425 AV WILLIAMS BUILDING COLLEGE PARK MD 20742
1	UNIVERSITY OF MARYLAND DR. BETSY MENDELSOHN 1125 CUMBERLAND HALL COLLEGE PARK MD 20742
1	UNIVERSITY OF MARYLAND DEPT OF ELECTRICAL & COMPUTER ENGINEERING BRIANNA MURPHY C/O STEVE NORTON 2425 AV WILLIAMS BUILDING COLLEGE PARK MD 20742
17	DIRECTOR US ARMY RESEARCH LAB RDRL SER E ROMEO DEL ROSARIO EDWARD VIVEIROS JOHN PENN KWOK TOM TONY IVANOV ROBERT PROIE ROGER KAUL THOMAS FARMER (5 COPIES) RDRL SER L MADAN DUBEY RONALD POLCAWICH JEFFREY PULSKAMP RDRL SED E SARAH BEDAIR RDRL SER M ARTHUR HARRISON 2800 POWDER MILL RD ADELPHI MD 20783-1197

ABERDEEN PROVING GROUND

No. of Copies	Organization
1	DIR USARL RDRL CIM G (BLDG 4600)