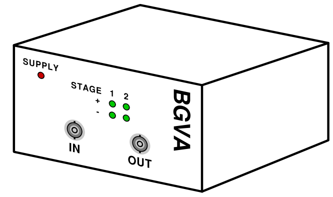
80 V BIPOLAR GATE VOLTAGE AMPLIFIER



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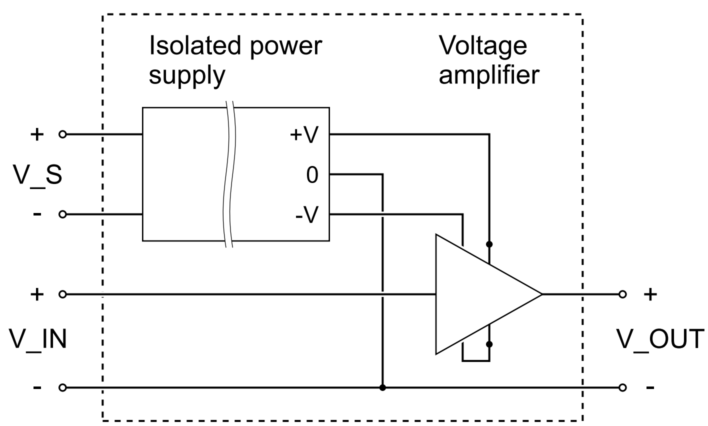
FEATURES

- 10× gain with 1% accuracy
- ±80 V output swing
- Single 15 V DC power supply, isolated from amplifier circuit
- 1 kHz bandwidth (1%)
- 1 mV_{rms} output noise[3]

DESCRIPTION

The digital-to-analog converters provided by the computer-based data acquisition cards used in many electrical characterization systems are typically limited to ±10 V. Larger voltage are occasionally required, however, necessitating a voltage amplifier of some sort. The bipolar gate voltage amplifier (BGVA) was designed and constructed to fill this need in the context of graphene electronics. It is capable of smoothly sweeping from –80 V to 80 V with 0.1% accuracy and has a nominal DC voltage gain of 10 V/V such that the required input voltage is limited to ±8 V. One prototype BGVA currently exists, but additional copies could easily be manufactured on a custom PCB.



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[3] Requires an external filter.

ABSOLUTE MAXIMUM RATINGS

Exceeding these ratings may cause permanent damage to the device.

Power supply voltage	17 V
Input voltage, un-powered	±3 V
Input voltage, powered	±10 V

OPERATION

The BGVA should be powered-up using a “soft start” procedure, as follows:

1. Switch on a DC power supply, set the output to 0 V, and the current compliance to approximately 250 mA.
2. Connect the power supply to the amplifier using “banana connector” leads.
3. Ramp the voltage to 15 V. The current compliance indicator on the power supply may flicker when passing through 4 V as the DC/DC converters come online.
4. Make the input and output connections.

The input should be disconnected or held at 0 V when the amplifier is not powered.

BUILT-IN PROTECTION

Although the BGVA is a prototype, it offers standard safety features such as limited short circuit protection and a fused supply connection. In the event that the power supply polarity is reversed, included protection diodes should prevent any damage.

SPECIFICATIONS

The BGVA requires a single 15 V external power supply, which is electrically isolated from the input and output connections, eliminating a potential ground loop. When paired with the (included) external filter, it produces no more than ≈1 mV_{rms} output noise while maintaining greater than 1 kHz of bandwidth.

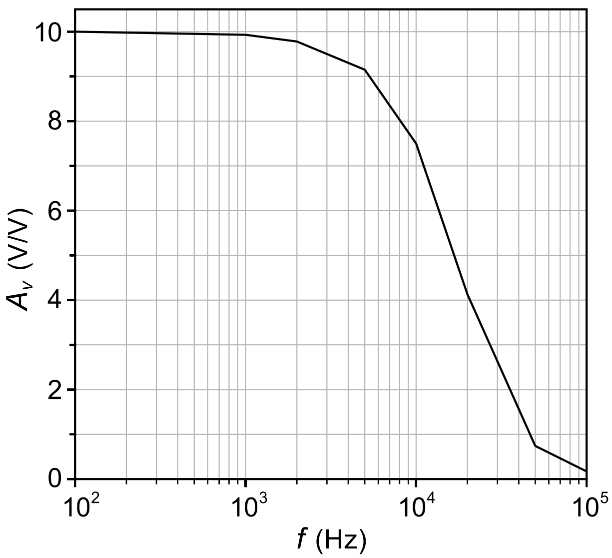
	Min.	Nom.	Max.	Unit
GAIN				
Voltage gain, DC	9.9	10.0	10.1	V/V
Bandwidth (1%)		1.2[4]		kHz
Bandwidth (–3 dB)		12.3[4]		kHz
INPUT				
Positive voltage		8.0	8.3	V
Negative voltage	–8.3	–8.0		V
Impedance, DC	-	1	-	MΩ
OUTPUT				
Positive voltage		80	83	V
Negative voltage	–83	–80		V
Impedance, DC	-	17.4[5]	-	kΩ
POWER SUPPLY				
Input voltage	14.5	15	15.5	V
Input current	130	160	180	mA
Fuse	-	0.5	-	A

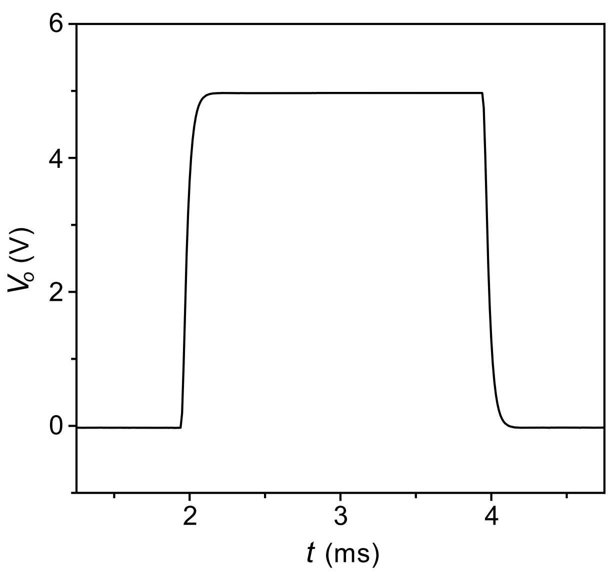
PERFORMANCE

The BGVA’s performance exceeds the requirements of simple DC gate sweep measurements. The voltage gain A_V for a sinusoidal input signal V_i is plotted below as a function of frequency f. The amplified signal V_o (measured the output of the external filter) falls to 1% of its DC value at

[4] The bandwidth is slightly greater without the external filter.
[5] The output impedance is 8 kΩ without the external filter.

1.2 kHz and is reduced by 3 dB at 12.3 kHz. The step response rises to 99% of its final value in 156 µs with no ringing or overshoot. (Without the external filter, rise time is 58 µs with a 0.3% overshoot.)





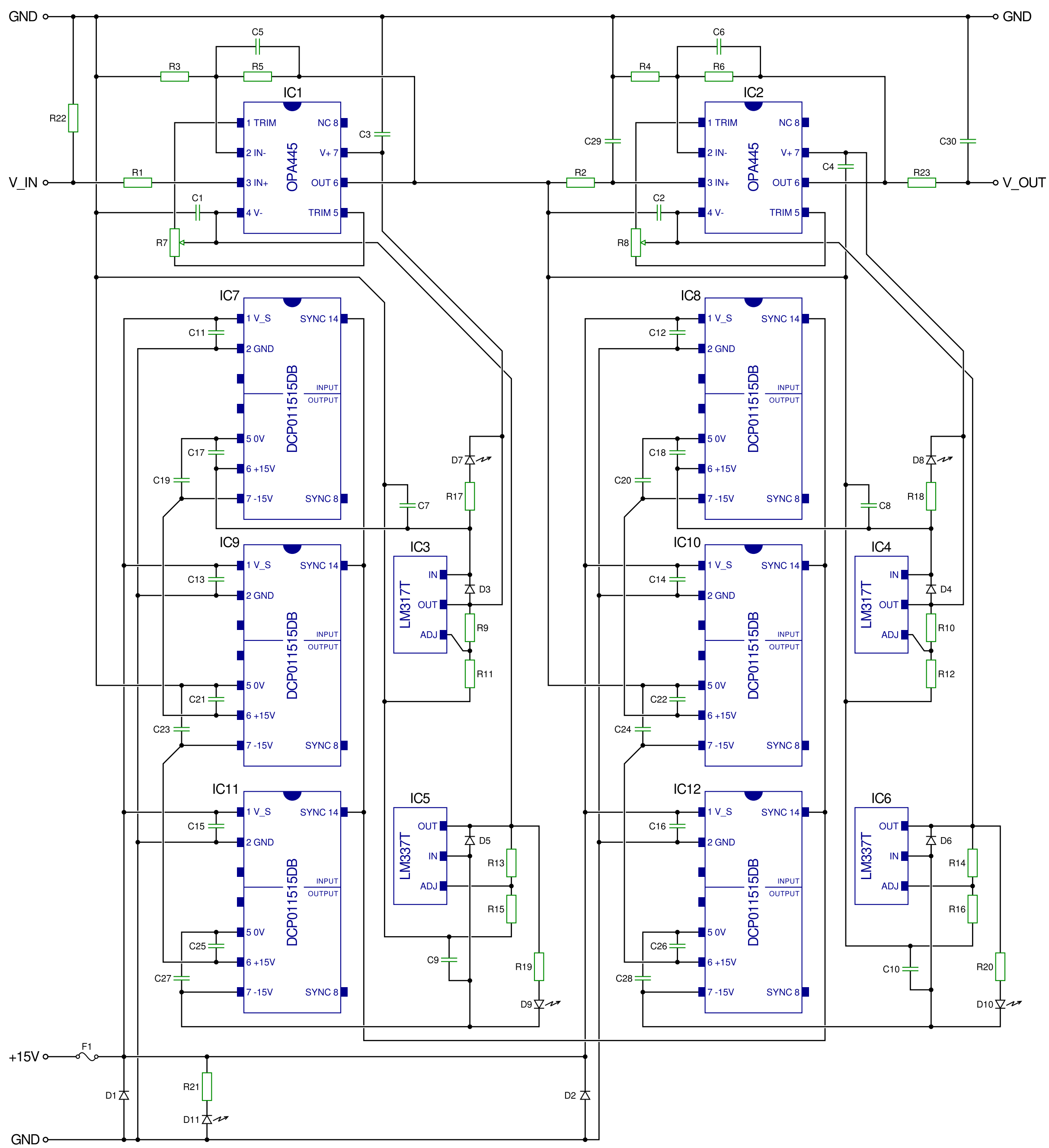
CIRCUIT DESIGN

The BGVA comprises two non-inverting, op-amp-based stages in series ($A_{V,1}$ = 5 V/V, $A_{V,2}$ = 2 V/V). This design reduces the required per-stage voltage swing to $\pm$40 V, enabling the use of widely-available TI OPA445 op-amps. Each stage is powered by three TI DCP011515DB isolated DC/DC converters connected in series to provide $\pm$45–47 V, which is then regulated down to $\pm$43 V by a pair of LM317/LM337 voltage regulators. The second stage's power supply is referenced to the output of the first stage, effectively level-shifting its supply rails V_{2-} and V_{2+} to match the required range. For example, given an input of 7 V, the interstage voltage V_o will be 35 V and V_{2-} and V_{2+} will be –8 V and 78 V, respectively. Thus, the 75 V output will fall safely within the second stage voltage rails.

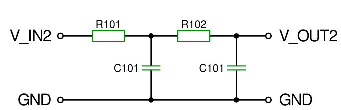
Power supply noise is controlled by 1 µF bypass capacitors (C11-C28) placed near the inputs and outputs of the DC/DC converters. In addition, large 4.7 µF tantalum capacitors (C1-C4) are placed near the supply terminals of the op-amps.

The TI DCP011515DB provides isolation by using an 800 kHz oscillator driving a integrated transformer, which is connected to a rectifier at the output. Inevitably, the transformers inductively couple to the circuit traces, generating high-frequency noise. This noise was significantly reduced, however, by a 15 kHz low-pass filter enclosed in a separate aluminum box.

MAIN CIRCUIT



EXTERNAL FILTER



COMPONENTS

Qty.	Type	Label	Value	Unit	Rating
2	OPA445AP	IC1,IC2	-		-
2	LM317T	IC3,IC4	-		-
2	LM337T	IC5,IC6	-		-
6	DCP011515DB	IC7-IC12	-		-
6	1N4002	D1-D6	-		1 A, 100 V
4	LED (green)	D7-D10	-		-
1	LED (red)	D11	-		-
1	fuse	F1	0.5	A	250 V
4	tantalum capacitor	C1-C4	4.7	µF	50 V
1	ceramic disc capacitor	C5	18	pF	1 kV
1	ceramic disc capacitor	C6	27	pF	1 kV
4	tantalum capacitor	C7-C10	1.0	µF	50 V
18	ceramic bypass capacitor	C11-C28	1.0	µF	50 V
1	ceramic disc capacitor	C29	47	pF	1 kV
1	ceramic disc capacitor	C30	560	pF	1 kV
1	ceramic disc capacitor	C101	688[6]	pF	1 kV
1	ceramic disc capacitor	C102	815[6]	pF	1 kV
1	resistor	R1	80.5[6]	kΩ	-
1	resistor	R2	118.6[6]	kΩ	-
1	resistor	R3	100.2[6]	kΩ	-
1	resistor	R4	244.0[6]	kΩ	-
1	resistor	R5	402[6]	kΩ	-
1	resistor	R6	243.2[6]	kΩ	-
2	trimming potentiometer	R7,R8	100	kΩ	-
1	resistor	R9	32.40[6]	kΩ	-
1	resistor	R10	32.12[6]	kΩ	-
1	resistor	R11	472[6]	kΩ	-
1	resistor	R12	465[6]	kΩ	-
1	resistor	R13	24.29[6]	kΩ	-
1	resistor	R14	24.30[6]	kΩ	-
1	resistor	R15	356.0[6]	kΩ	-
1	resistor	R16	356.2[6]	kΩ	-
4	resistor	R17-R20	2	kΩ	-
1	resistor	R21	10	kΩ	-
1	resistor	R22	1	MΩ	-
1	resistor	R23	8	kΩ	-
1	resistor	R101	5.51[6]	kΩ	-
1	resistor	R102	3.875[6]	kΩ	-

[6] This value is critical to the operation of the circuit and should be replaced within the tolerance indicated number of significant figures provided.