Report

High Speed Piezo Driver

V6 26/08/2015

Aim

Feasibility study of a high speed piezo driver

Requirements

Driving a piezo brick up to 500 kHz with a full voltage range [0, 150] V.

Design Data

Capacitive Load (piezo brick) = 170nF

Required Slew rate (sine wave) = 2*pi* f * V_{peak} =2*pi*(500e3)* 75 * (1e-6) V/µs = ~235 V/µs

Required Peak Current = C dV/dt = 170 nF * 235 V/µs = ~40 A

Possible Candidate

Power Operational Amplifier Apex MP111

FEATURES

- LOW COST
- HIGH VOLTAGE - 100 VOLTS
- HIGH OUTPUT CURRENT- 50 AMP PULSE OUTPUT, 15 AMP CONTINUOUS
- 170 WATT DISSIPATION CAPABILITY
- 130 V/µS SLEW RATE
- 500kHz POWER BANDWIDTH

APPLICATIONS

- INKJET PRINTER HEAD DRIVE
- PIEZO TRANSDUCER DRIVE
- INDUSTRIAL INSTRUMENTATION
- REFLECTOMETERS
- ULTRA-SOUND TRANSDUCER DRIVE

Main Issues

- Voltage peak
- Slew Rate

Possible Solution

From Apex AN 20:

5.2 UNIPOLAR OUTPUT

A particularly powerful way of applying the bridge is in the unipolar bridge. By unipolar, we mean that the output can only swing from 0 to one polarity. Figure 5 is used to illustrate this technique.

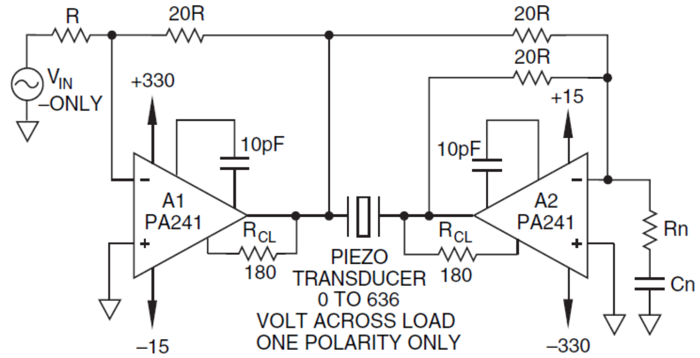


FIGURE 5.

This solution could fulfil all the requirements (using two Apex MP111).

In this case, supposing that the master amplifier (on the left) output works between 0 V and 75 V and the slave one (on the right) instead between 0V and -75V, the floating voltage across the piezo brick (V1 – V2) will be in the range [0, 150] V.

In particular when the master reaches 75V the slave reaches -75 V so V1 – V2 =150V.

<u>The design data</u> with this solution will change because the voltage swing of the single Apex MP111 is halved.

Capacitive Load (piezo brick) = 170nF

Required Slew rate (sine wave) = 2*pi* f *V_{peak} =2*pi*(500e3)* 37.5 * (1e-6) V/µs = ~117.8 V/µs

Required Peak Current = C dV/dt = 170 nF * 117.8 V/µs = ~20 A

With this solution the previous two issues on the Slew Rate and Voltage Output are solved.

Supply Rails

From Apex MP111 datasheet, there are two supply rails Vs and Vb that can be the same for avoiding that Vb is less than Vs.

With Vs=Vb=85V an output voltage of 75V can be reached (Vs - 8.4 from the datasheet).

With –Vs=–Vb=–20V an output voltage of 0V can be reached (-Vs +5.8).

Moreover, the Common Mode Voltage Range requirement (15V from the datasheet) is fulfilled.

Power Dissipation

The power that should be dissipated in the amplifier can be computed as

$P_{ampl} = P_{supply} - P_{load}$

Considering the dielectric losses in the piezo brick:

$P_{load} = (\pi/4) *\tan(\delta) *f *C * (V_{pp})^2 = (pi/4)*0.3*(500e3)*(170e-9)*(150)^2 = 450.6$ W

This P_{load} should be halved due to the circuit symmetry.

For each side of the bridge $P_{supply} = 2V_sI_{peak}/\pi = 2*52.5*20/\pi = \sim 668.5$W.

So the power amplifier should dissipate $P_{ampl} = \sim 443$ W.

From the datasheet the maximum power that can be dissipated in the Apex MP111 can be computed as $P_{amplmax} = (T_j - T_a)/R_{jc} = (175-25)/0.65$ W = ~231 W. that is well below the needed one.

➔ A possible solution is to use 2 power amplifiers in parallel for each side of the bridge. In this case the power that should be dissipated is halved as in Apex AN 20

5.4 PARALLEL CONNECTION

The bridge circuit can also be combined with the paralle connection of power op amps. Figure 7 shows how substantia audio power outputs can be obtained along with improved reliability since the parallel connection spreads the load amonc more amplifiers.

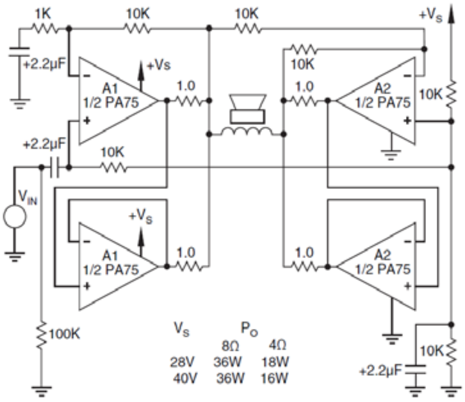


FIGURE 7. SINGLE SUPPLY PARALLEL BRIDGE

In this case the Heat sink thermal resistance can be computed according to

$R_{HT} = (T_j - T_a)/P_D - R_{jc} = ((175-25)/221.6)-0.65 = 0.0269$ °C/W (this is a max value).

Further Considerations

- Heat Dissipation of the Piezo Brick. Its maximum operating temperature is 150 °C. With the considered condition also 100 °C of temperature rise could be expected.
- Considering other piezo bricks with lower capacitance (e. g 3mm*3mm with 65nF or 2mm*2mm with 25nF that have all the same nominal stroke and driving voltage). All the critical parameters will be scaled by the ratio between the capacitances.
- Considering the stability issues of the driving circuit with 4 power op amp (2 in parallel for each side of the bridge).
- Considering maybe a mechanical amplification mechanism on the piezo brick -> the driving voltage can be reduced almost by the same factor.

Evaluation of the use of a lower capacitance brick (e.g. NAC 2011 - 2mm*2mm)

- **Design Data**

Capacitive Load (piezo brick) = 25nF

Required Slew rate (sine wave) = 2*pi* f * V_{peak} =2*pi*(500e3)* 75 * (1e-6) V/µs = ~235 V/µs (it doesn't change)

Required Peak Current (sine wave) = C dV/dt = 25 nF * 235 V/µs = ~ 6 A

Required Slew rate (triangular wave) = 4* f * V_{peak} = 4*(500e3)* 75 * (1e-6) V/µs = 150 V/µs

Required Peak Current (triangular wave) = C dV/dt = 25 nF * 150 V/µs = 3.75 A

- **Solution with 2 MP111 in bridge configuration:**

Required Slew rate (sine wave) = 2*pi* f *V_{peak} =2*pi*(500e3)* 37.5 * (1e-6) V/µs = ~117.8 V/µs (it doesn't change)

Required Peak Current = C dV/dt = 25 nF * 117.8 V/µs = ~ 3 A

Required Slew rate (triangular wave) = 4* f * V_{peak} = 4*(500e3)* 37.5 * (1e-6) V/µs = 75 V/µs

Required Peak Current (triangular wave) = C dV/dt = 25 nF * 75 V/µs = ~1.88 A

- **Power Dissipation**

The power that should be dissipated in the amplifier can be computed as

$P_{ampl} = P_{supply} - P_{load}$

Considering the dielectric losses in the piezo brick:

$P_{load} = (\pi/4) *\tan (\delta) *f *C * (V_{pp})^2$=(pi/4)*0.3*(500e3)*(25e-9)*$(150)^2$ = 66.3 W

This P_{load} should be halved due to the circuit symmetry ($P_{loadhalf}$=33.15W).

For each side of the bridge $P_{supply} = 2V_sI_{peak}/\pi$ = 2*52.5*3/ π = ~ 100.3W.

So the power amplifier should dissipate $P_{ampl} = 67.15$ W.

From the datasheet the maximum power that can be dissipated in the Apex MP111 can be computed as $P_{amplmax} = (T_j - T_a)/R_{jc} = (175\text{-}25)/0.65$ W = ~231 W.

For the heat sink

$R_{HT} = (T_j - T_a)/P_D - R_{jc} = ((175\text{-}25)/67.15)\text{-}0.65 = 1.58$ °C/W (this is a max value).

Circuit (functional) Simulation

5.2 UNIPOLAR OUTPUT

A particularly powerful way of applying the bridge is in the unipolar bridge. By unipolar, we mean that the output can only swing from 0 to one polarity. Figure 5 is used to illustrate this technique.

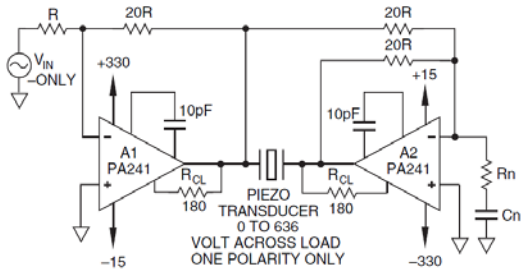
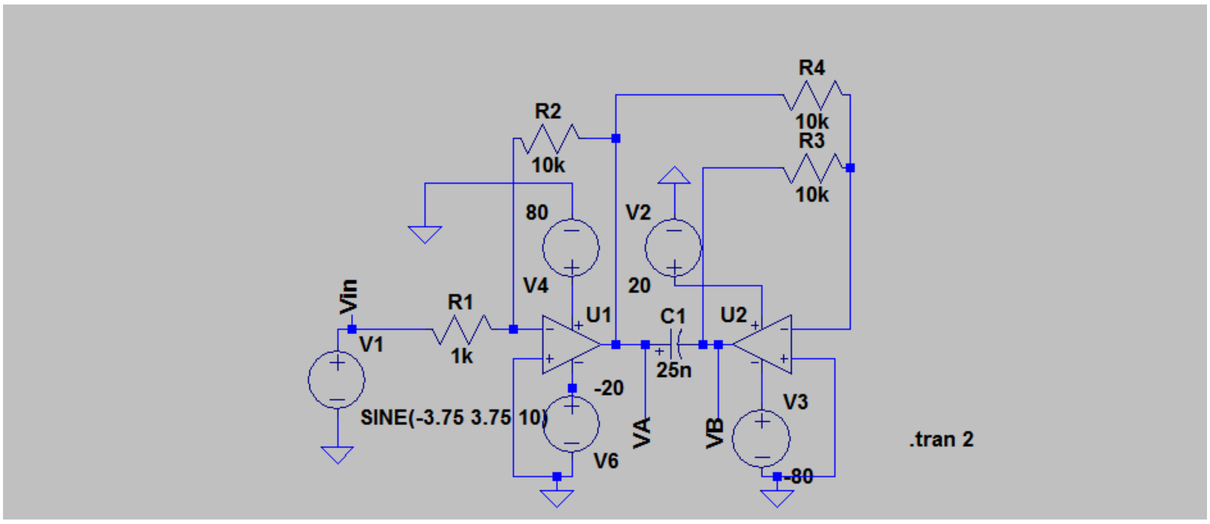
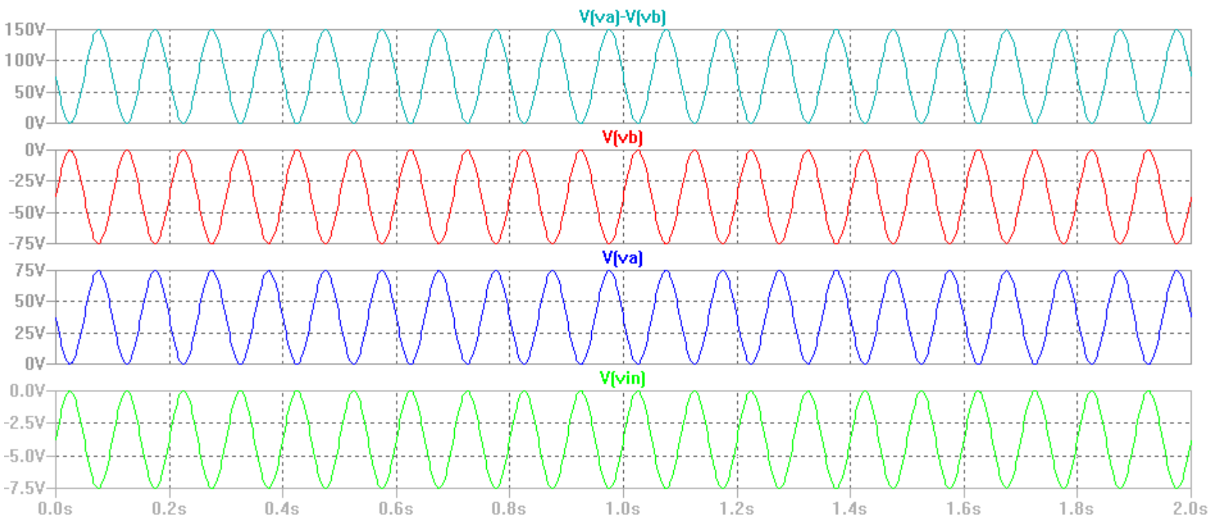
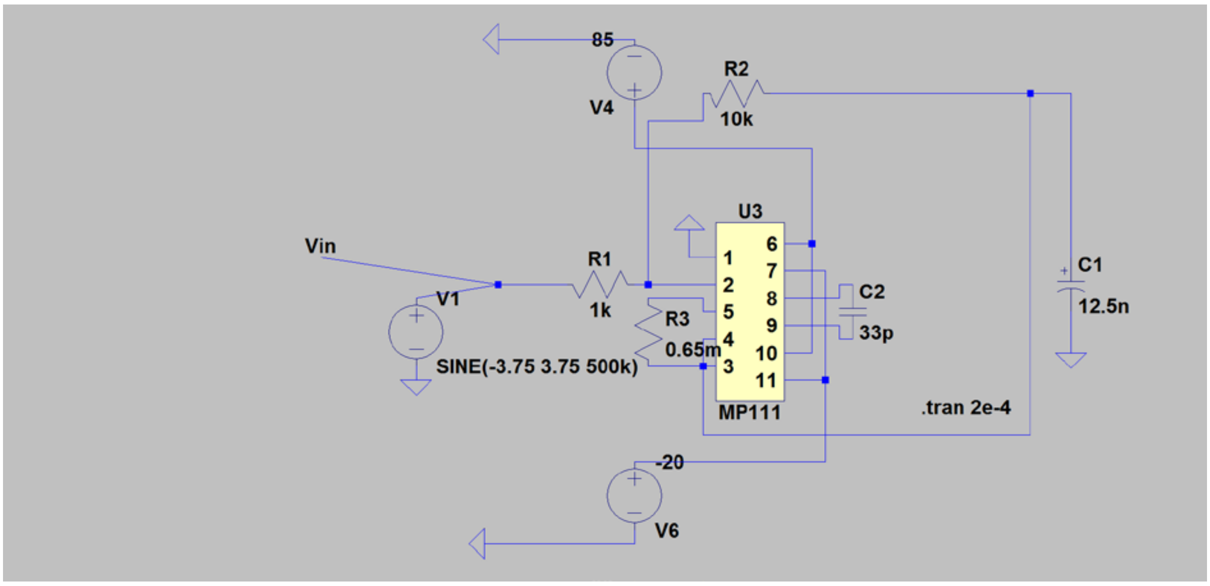


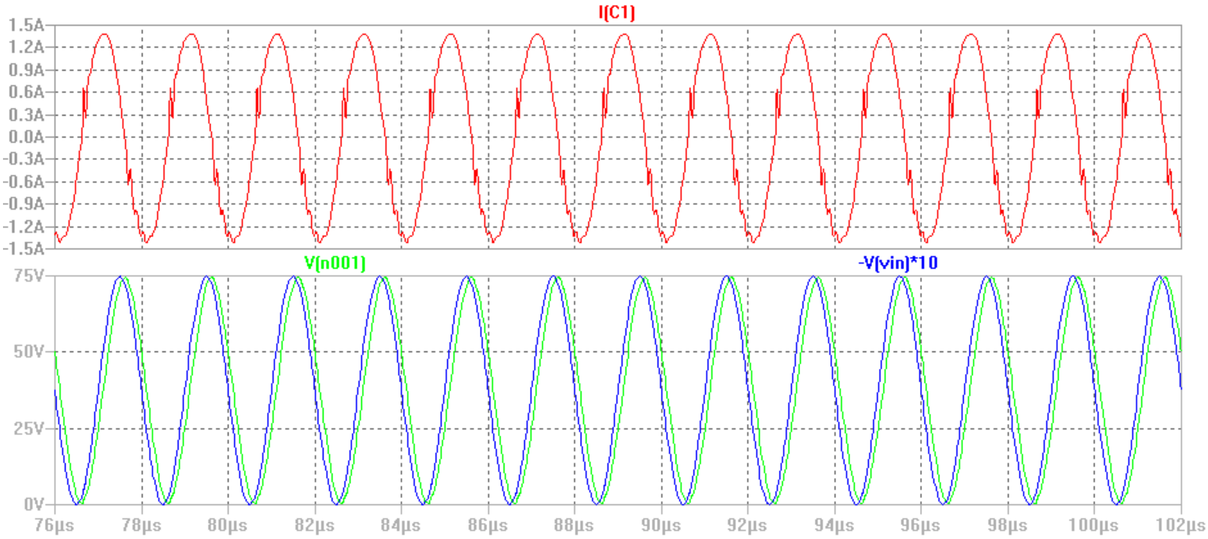
FIGURE 5.



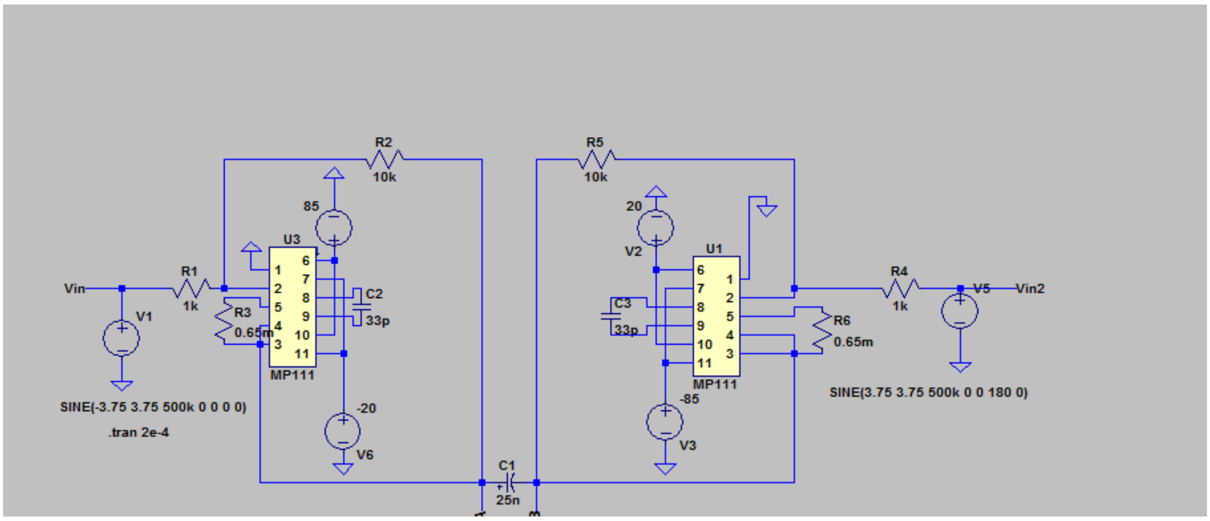


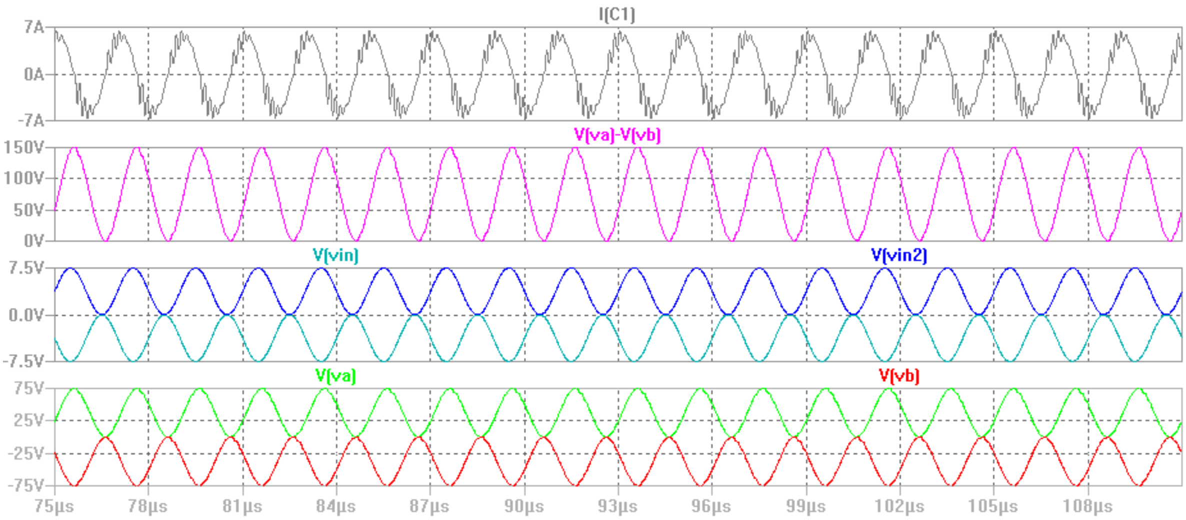
Circuit Simulation with a single Apex MP111





Circuit Simulation with a two Apex MP111 in a modified bridge





Note: the bridge has been modified because the slave MP111 in unit gain operation has a slew rate limitation (due to the compensation capacitor that should be bigger).

PHASE COMPENSATION

C_C	GAIN W/O BOOST	TYP. SLEW RATE
100pF	≥1	55 V/µS
68pF	≥4	60 V/µS
33pF	≥10	130 V/µS

C_C	GAIN W BOOST	TYP. SLEW RATE
470pF	≥3	12 V/µS
220pF	≥6	27 V/µS
100pF	≥10	55 V/µS