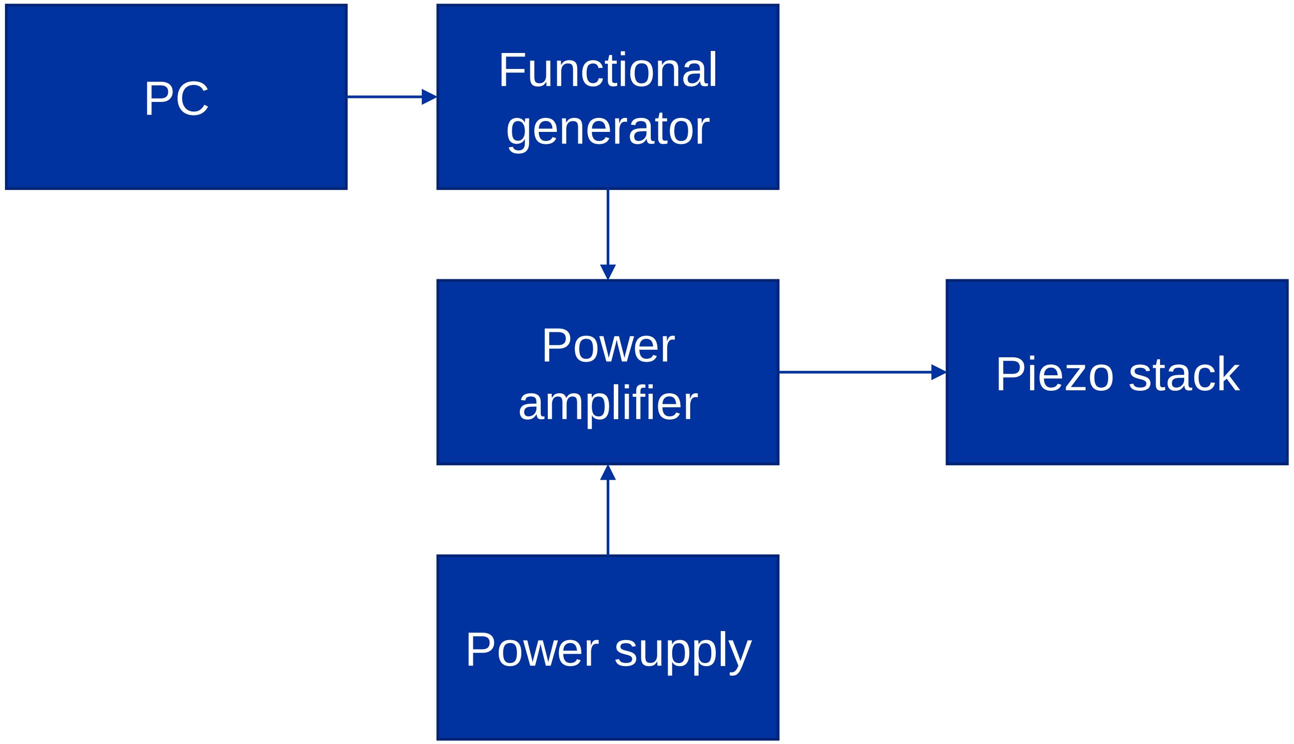
High speed PA testbench for studying vibrations on preloaded piezo actuators

Marta Alfonso

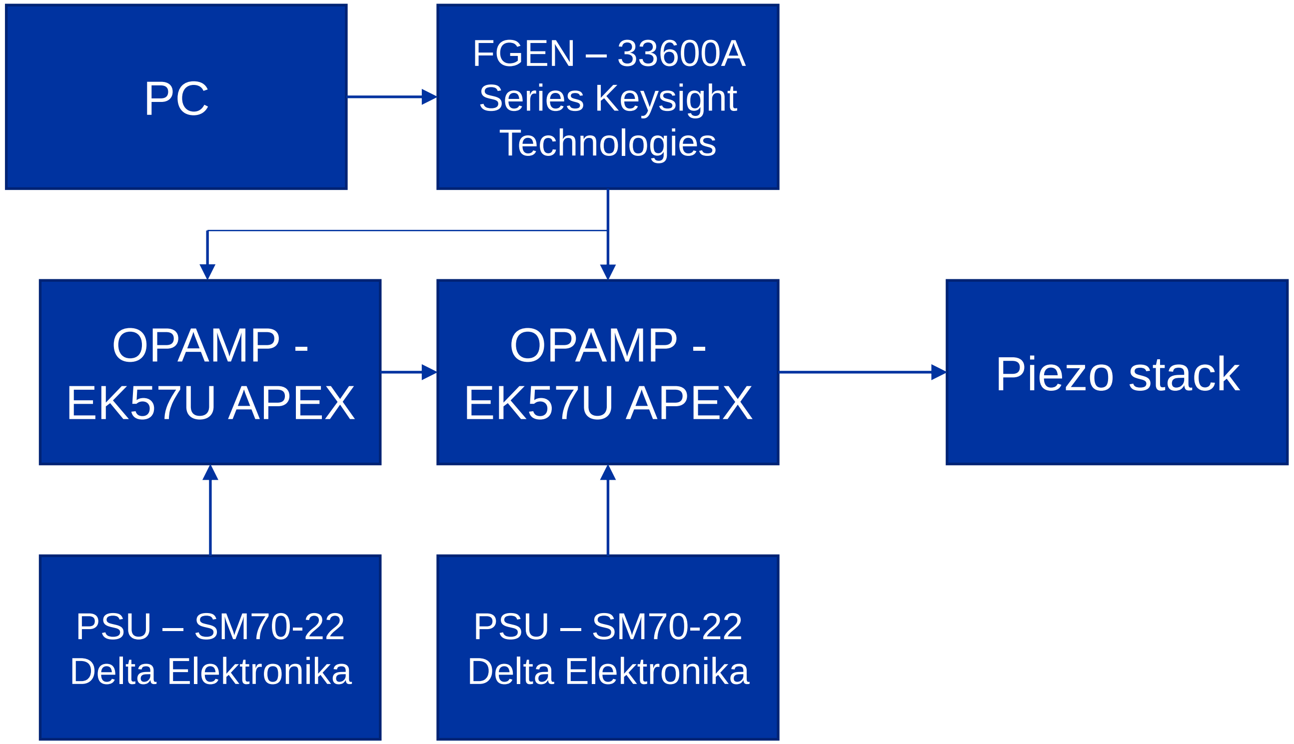
26-05-2023

List of contents

Architecture of the system



Overview of the proposed solution



Requirements of the system

- **Driving a piezoelectric brick up to 500 kHz with a full voltage range of 0 to 150 V.**
- **User interface enabling remote generation of vibrations.**
  - API for configuration of the function generator that gives the input signal for the system.
  - GUI for controlling and monitoring? the system from the PC.
- **A stand-alone chassis encapsulating the amplifier.**
  - Rack mountable
  - Ventilation

Electrical design: requirements

- **Voltage range [0, 150] V**
- **Capacitive load (piezo brick) = 170 nF**
- **Required slew rate (sine wave)**

$$SR = 2 \cdot \pi \cdot f \cdot V_{peak} = \frac{2 \cdot \pi \cdot 500\,kHz \cdot 75\,V}{10^6} \frac{V}{\mu s} \approx 235 \frac{V}{\mu s}$$

- **Required peak current**

$$I = C \cdot \frac{dV}{dt} = 170\,nF \cdot 235 \frac{V}{\mu s} \approx 40\,A$$

Electrical design

- **Chosen amplifier: APEX MP111u**

FEATURES

- Low Cost
- High Voltage - 100V
- High Output Current- 50A Pulse Output, 15A Continuous
- 170W Dissipation Capability
- 130V/µs Slew Rate
- 500 kHz Power Bandwidth

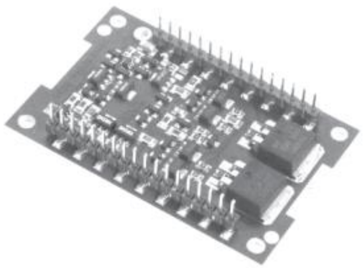
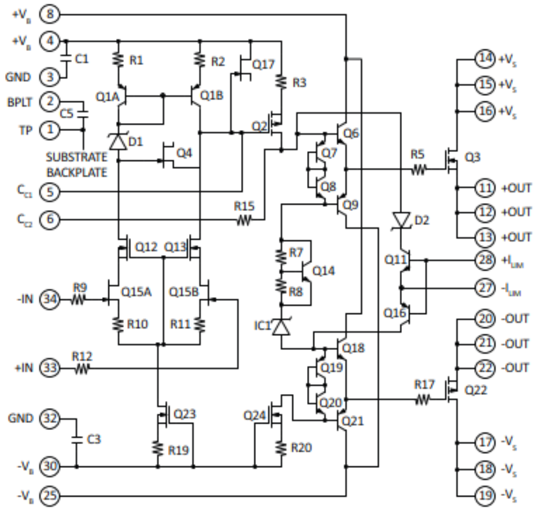
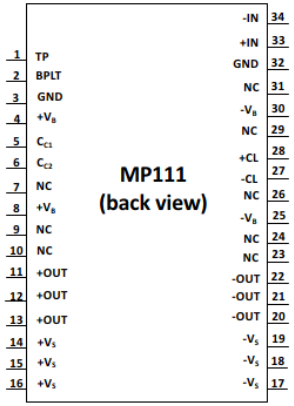


Figure 1: Equivalent Schematic



EXTERNAL CONNECTIONS

Figure 3: Pin-out



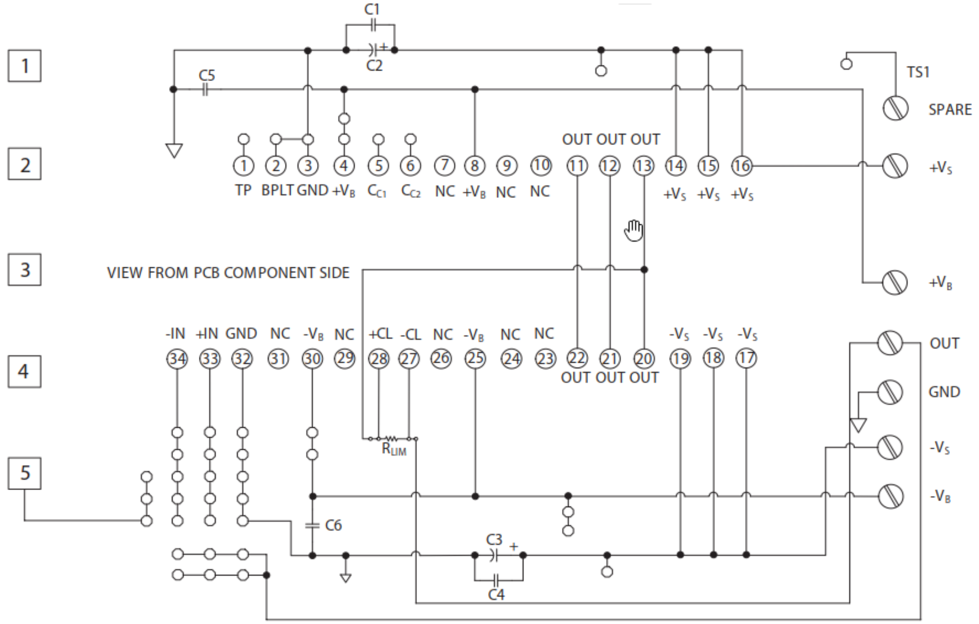
Pin Number	Name	Description
1	TP	Apex test pin, do not connect.
2	BPLT	AC coupling to backplate. Connect to signal ground.
3, 32	GND	Ground. Pins 3 and 32 are not connected on the unit. Connect both pins to system signal ground.
4, 8	$+V_B$	The positive boost supply rail. Short to $+V_S$ if unused. See applicable section.
5, 6	C_C	Compensation capacitor connection. Select value based on Phase Compensation. See applicable section.
11, 12, 13	+OUT	The positive current output. Short to -OUT pins. Connect these pins to the MP111 side of the current limit resistor and the +CL pin. Output current is sourced from these pins through the current limit resistor and to the load.
14, 15, 16	$+V_S$	The positive supply rail.
17, 18, 19	$-V_S$	The negative supply rail.
20, 21, 22	-OUT	The negative current output. Short to +OUT pins. Connect these pins to the MP111 side of the current limit resistor and the +CL pin. Output current sinks to these pins through the current limit resistor from the load.
25, 30	$-V_B$	The negative boost supply rail. Short to $-V_S$ if unused. See applicable section.
27	-CL	Connect to the load side of the current limit resistor and feedback resistor. Current limit will activate if the voltage across R_{CL} exceeds 0.65V.
28	+CL	Connect to the OUT side of the current limit resistor. Current limit will activate if the voltage across R_{CL} exceeds 0.65V.
33	+IN	The non-inverting input.
34	-IN	The inverting input.
All Others	NC	No Connection.

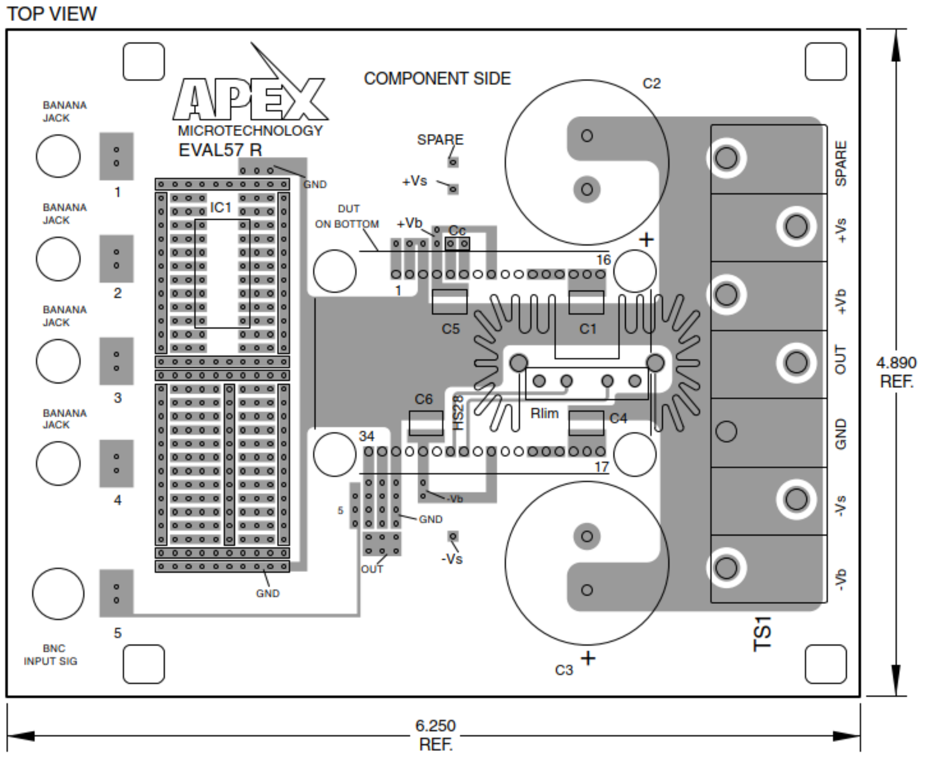
Electrical design

- **Implemented with the APEX EK57 evaluation kit**

FEATURES

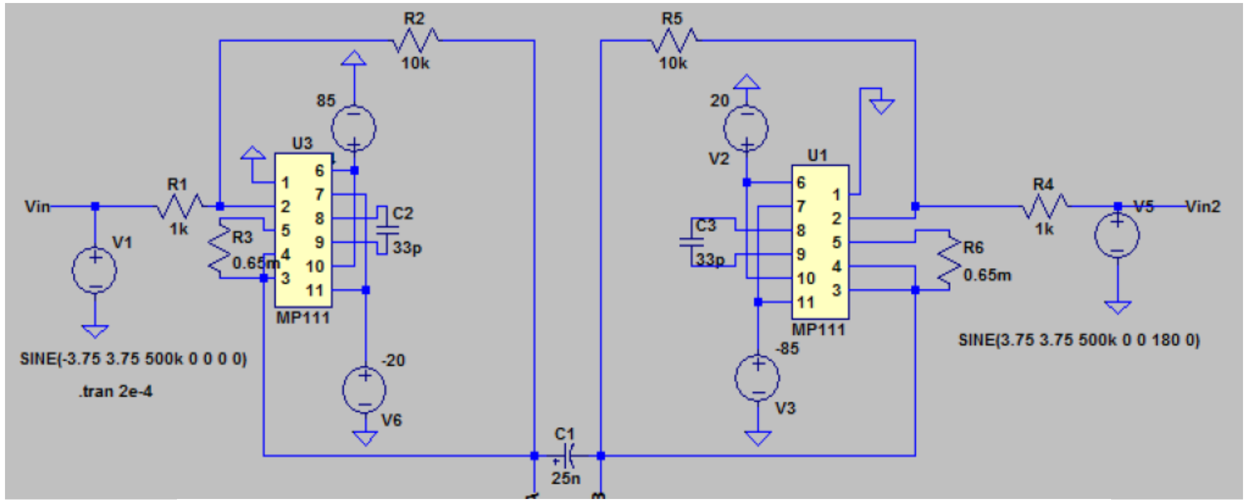
- Low Cost
- High Voltage - 100V
- High Output Current- 50A Pulse Output, 15A Continuous
- 170W Dissipation Capability
- 130V/µs Slew Rate
- 500 kHz Power Bandwidth

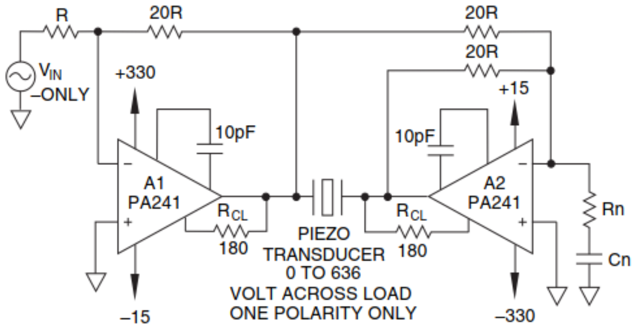


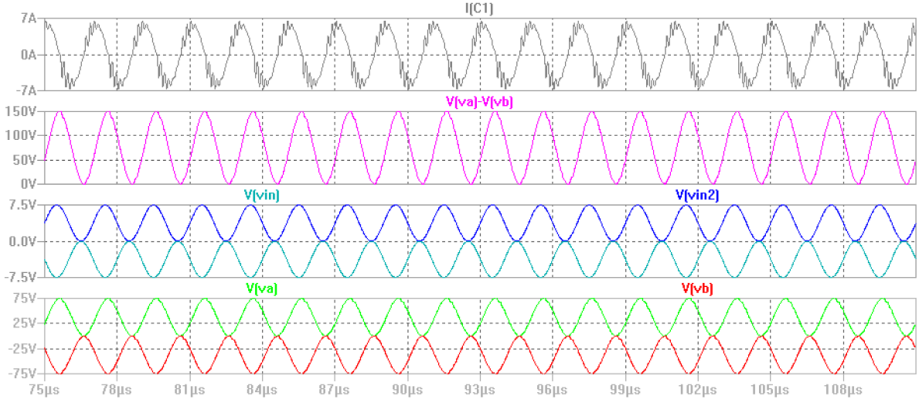


Electrical design

- **Unipolar bridge configuration with two amplifiers**
  - For a total voltage swing of 0 to 150 V
    - Voltage swing of master amplifier
      - 0 to 75 V, Vpk = 37.5 V
    - Voltage swing of slave amplifier
      - 0 to -75 V, Vpk = -37.5 V
  - Required slew for each opamp (Vpk=37.5 V)
    - 117.8 V/µs
  - Required peak current
    - 20 A







Electrical design

- **Modified unipolar bridge configuration with two amplifiers**
  - Supply rails
    - Report says +Vs = 85 V to have a maximum output of +Vs – 8.4 ≈ 75 V
    - And –Vs =-20 V to have a minimum output of –Vs ≈ -14.2 V
    - Input *common mode* range taking Vcm into account: +Vs – 15 V = 70 V and –Vs + 15 V = -5 V
    - Datasheet:

POWER SUPPLY

Parameter	Test Conditions	Min	Typ	Max	Units
Voltage		±15	±45	±50	V

OUTPUT

Parameter	Test Conditions	Min	Typ	Max	Units
Voltage Swing	I_{OUT} = 15A	$+V_S$ - 10	$+V_S$ - 8.4		V
Voltage Swing	I_{OUT} = -15A	$-V_S$ + 10	$-V_S$ + 5.8		V
Voltage Swing	I_{OUT} = 15A, $+V_B$ = $+V_S$ +10V	$+V_S$ - 0.8			V
Voltage Swing	I_{OUT} = -15A, $-V_B$ = $-V_S$ -10V	$-V_S$ + 1.0			V
Current, continuous, DC		15			A
Slew Rate, A_V = -20	C_C= 33pF	100	130		V/µs
Settling Time to 0.1%	2V step		1		µs
Resistance	No load, DC		3		Ω

ABSOLUTE MAXIMUM RATINGS

Parameter	Symbol	Min	Max	Units
Supply Voltage, total	$+V_s$ to $-V_s$		100	V
Supply Voltage [1]	$+V_B$		$+V_S$ +15	V
Supply Voltage [1]	$-V_B$		$-V_S$ -15	V
Output Current, peak, within SOA	I_{OUT}		50	A
Power Dissipation, internal DC	P_D		170	W
Input Voltage, common mode	V_{CM}		$+V_B$ to $-V_B$	V
Input Voltage, differential	$V_{IN\ (Diff)}$	-25	+25	V
Temperature, pin solder, 10s max.			225	°C
Temperature, junction [2]	T_J		175	°C
Temperature Range, storage		-40	+105	°C
Operating Temperature Range, case	T_C	-40	+85	°C

1. Power supply voltages $+V_B$ and $-V_B$ must not be less than $+V_S$-0.6V and $-V_S$+0.6V respectively.
2. Long term operation at the maximum junction temperature will result in reduced product life. Derate internal power dissipation to achieve high MTTF.

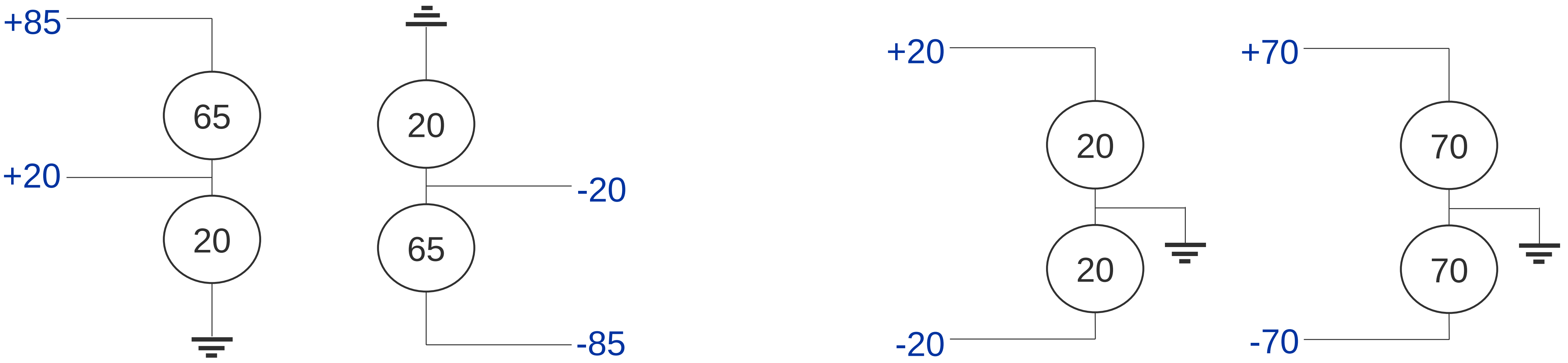
INPUT

Parameter	Test Conditions	Min	Typ	Max	Units
Offset Voltage, initial			1	5	mV
Offset Voltage vs. Temperature	Full temp range		50		µV/°C
Offset Voltage vs. Supply				20	µV/V
Bias Current, initial [1]				100	pA
Bias Current vs. Supply				0.1	pA/V
Offset Current, initial				50	pA
Input Impedance, DC			10^{11}		Ω
Input Capacitance			4		pF
Common Mode Voltage Range				$\pm V_B$-/+15	V
Common Mode Rejection, DC		92			dB
Noise	1 MHz BW, R_S = 1 kΩ		10		µV RMS

1. Doubles for every 10°C of case temperature increase.

Electrical design: power supply

- **Modified unipolar bridge configuration with two amplifiers**
  - Supply rails
    - +Vs = 85 V to have a maximum output of +Vs – 8.4 ≈ 75 V
    - And –Vs =-20 V to have a minimum output of –Vs ≈ -14.2 V
  - Available power supplies:
    - 2 x Delta Elektronika SM 70-22 → output range of 0-70 V, 22 A
    - Delta Elektronika SM 35-45 → output range of 0-35 V, 45 A
    - KEPCO BOP50 → output range of ±50 V, ± 4 A



Software design

- **API for the remote configuration of the function generator.**
  - Python interface with Agilent 33600A series function generator.
  - Use of PyVISA library with Keysight’s VISA driver for PC.
  - Configuration of the instrument with SCPI commands.

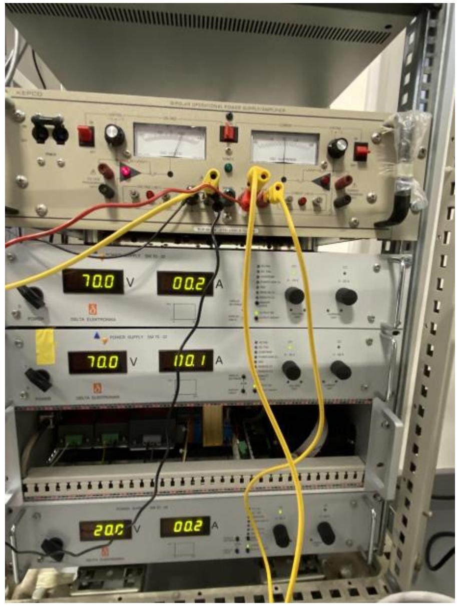
Software design

- **User interface**
  - Control of one or both input signals for the two amplifiers of the bridge configuration.
  - Setting of vibration characteristics: Amplitude and Frequency.
  - Visualization of the generated signals as well as signal across the piezo load.
  - Logging and reporting features.

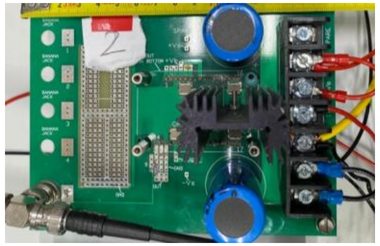
Mechanical design

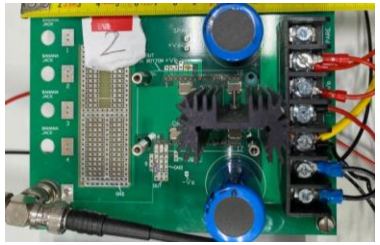
- **System on rack**
  - Encapsulation of the power amplifiers in a subrack
  - Power supplies and generator mounted on the rack as well
  - PXI?
- **Opamps subrack**
  - Front panel and back panel connections with other instruments
  - ON/OFF general switch?
  - Emergency stop button?
- **Preloaded piezo stacks mounting**
  - Piezo support? Mounting?
  - Measurement system: interferometers?
- **Also needed to include in the rack:**
  - Measurement systems: vibrometer, interferometer?

Mechanical design: rack configuration

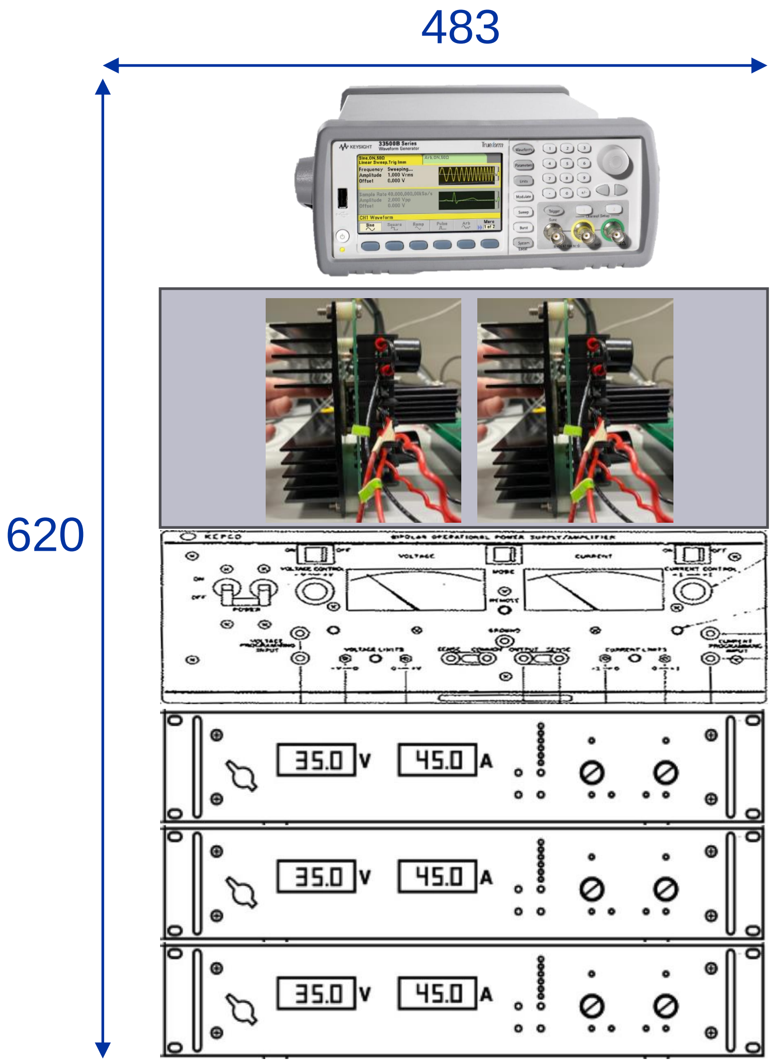


+



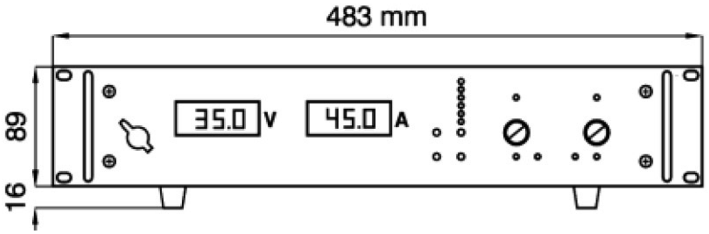


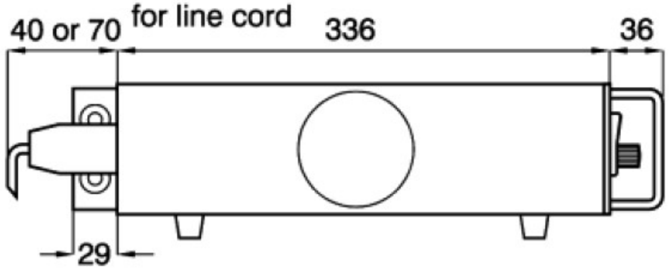
+

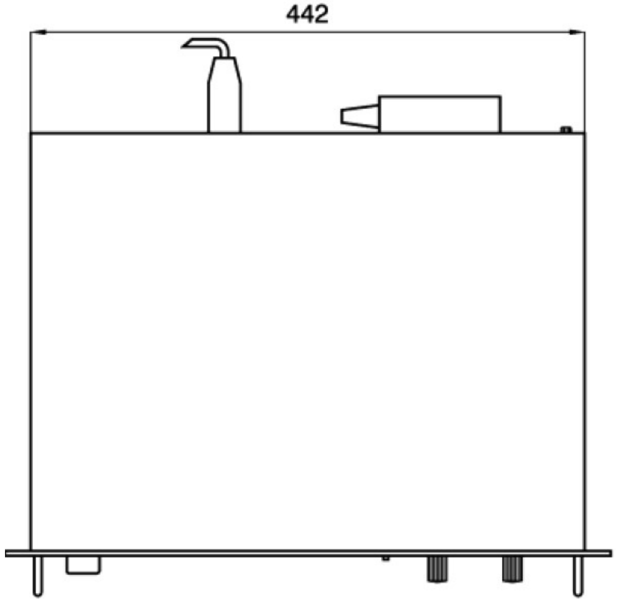


Mechanical design: devices

- We find three power supplies of the following model:

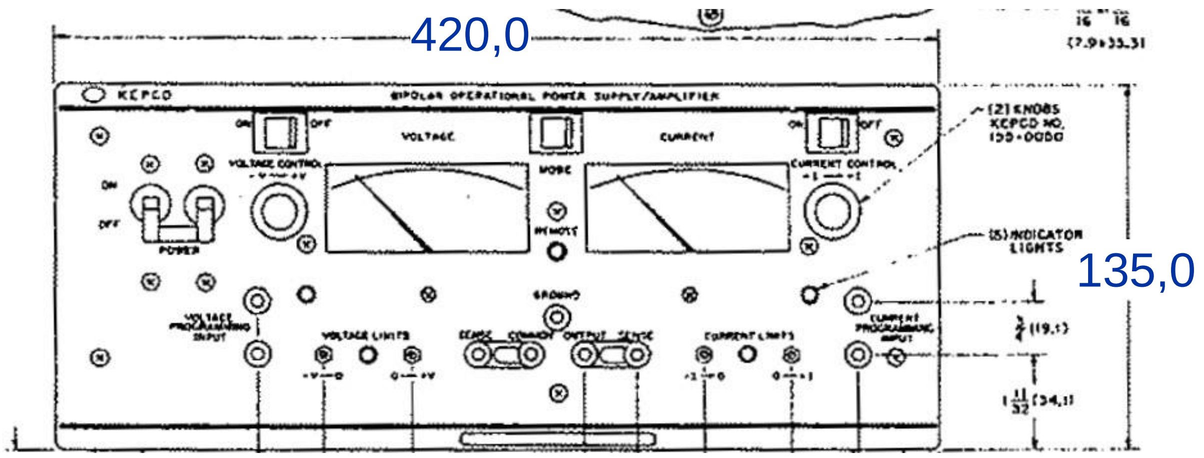


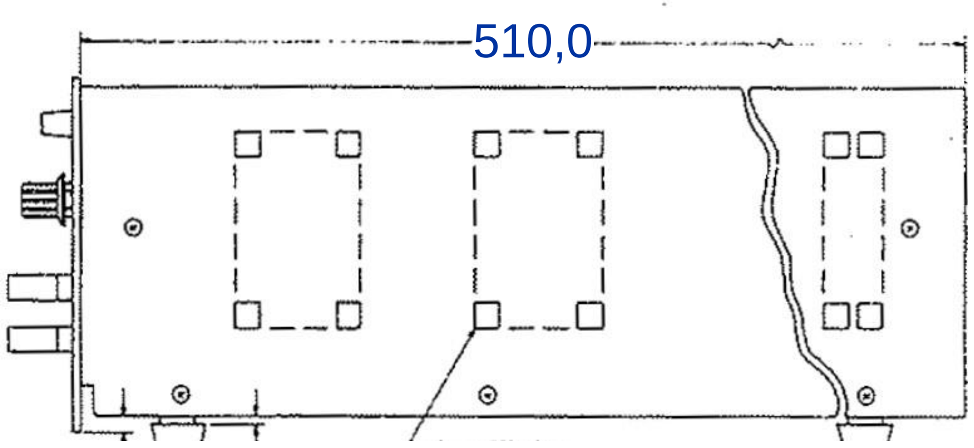




Mechanical design: devices

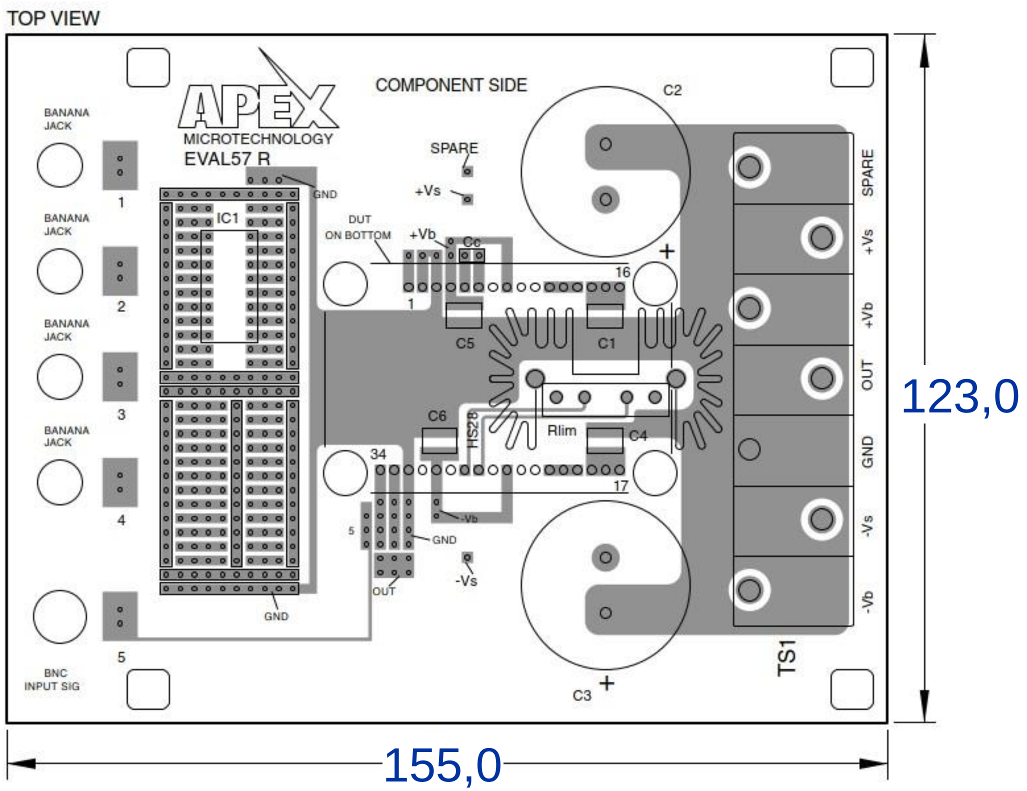
- We find one power supply of the following model:

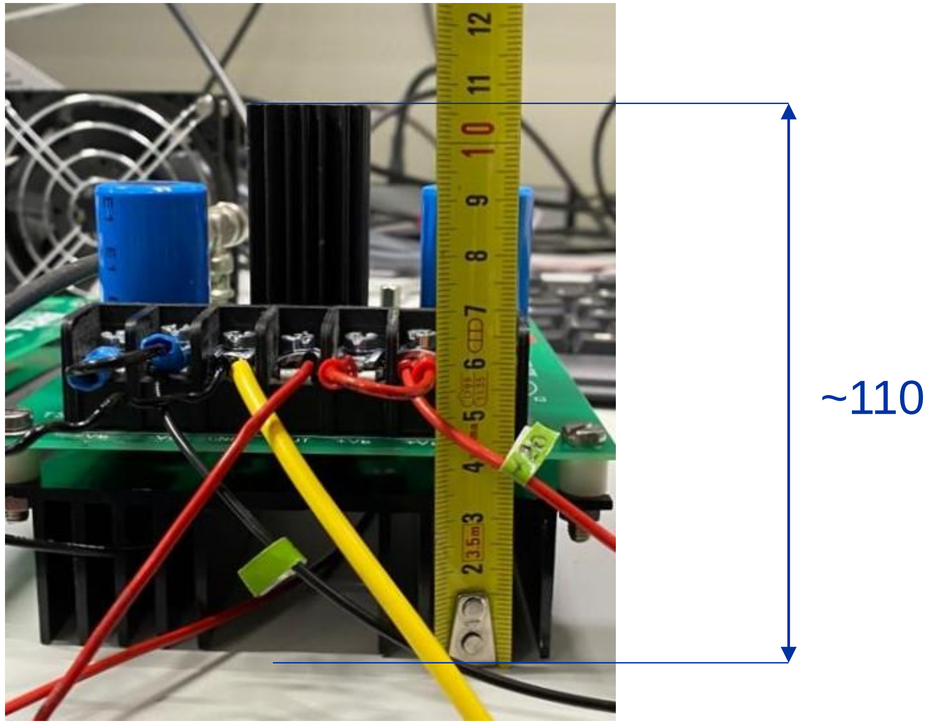




Mechanical design: devices

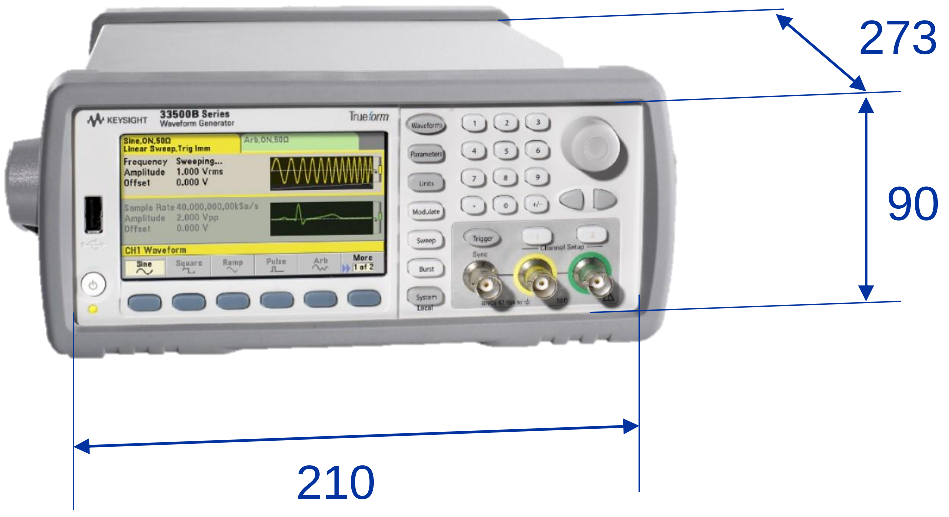
- We find two power opamps that will need a **subrack** case and **fans**:





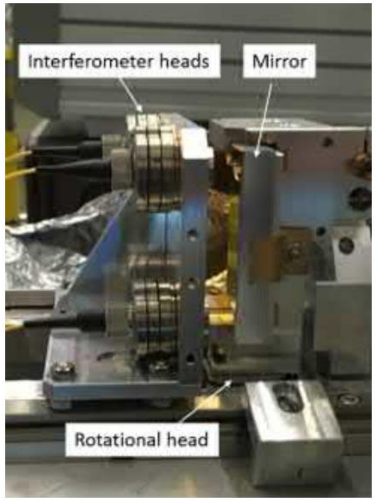
Mechanical design: devices

- We find one signal generator of the following model. Note that the grey protection is not present in the unit being used.

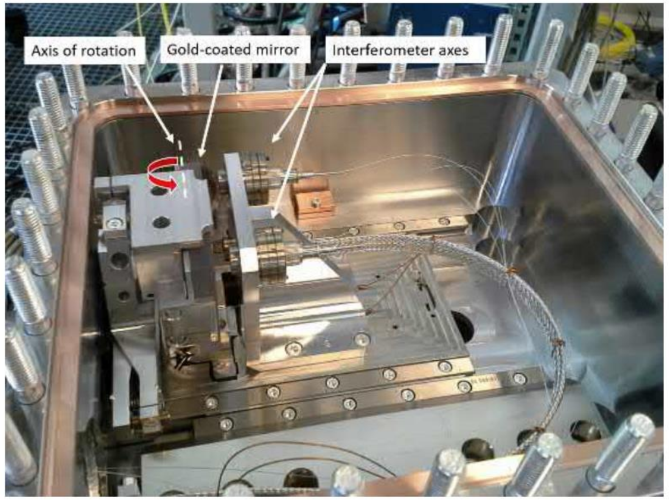


Measurements

- **Measurements performed with the piezo stack mounted in the piezogoniometer?**
- **Different/new structure for the testbench?**
- **Moving part (piezo) vs fixed part (measurement system)**
- **Relative or absolute measurements?**
- **Which measurements?**
  - Angle of displacement? Distance of displacement?
  - Speed? Acceleration?
  - Frequency? Voltage amplitude?
- **Which instruments?**
  - Interferometer?
  - Vibrometer?



(a) Dual-interferometer based angular measurement system.



(b) UHV tank with the rotational stage and angular measurement system. The crystal (not visible in the picture) is below the rotational stage.

Figure 2-16: Rotational stage with angular measurement system used in the piezo goniometers.

System validation

- **Experiments to validate the system**

Troubleshooting

- **Problem #1: one of the amplifiers doesn’t work** home.cern