Hardware manual of dexterous tweezers

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1 Overview

The prototype tweezers for micro-manipulation are placed on the fixed blocks. One finger of tweezers is perpendicular to the other finger. Unlike the usual parallel configuration of tweezers, the perpendicular configuration makes it possible to rotate a micro-component by controlling the deflection of each arm of tweezers separately.

Each finger of the tweezers is pushed and bent by its piezoelectric actuator. The deflection of finger is controlled by the voltage to the piezoelectric actuator. It is possible to measure the deflections and the forces of both fingers by the strain gauges attached to the base and the tip sheets.

The PCB substrate is on the XYZ stage. The stage is actuated by stepping motors in the X, Y and Z directions. We supply a micro-component on the substrate and move the substrate stage so that the tweezers can manipulate the component.

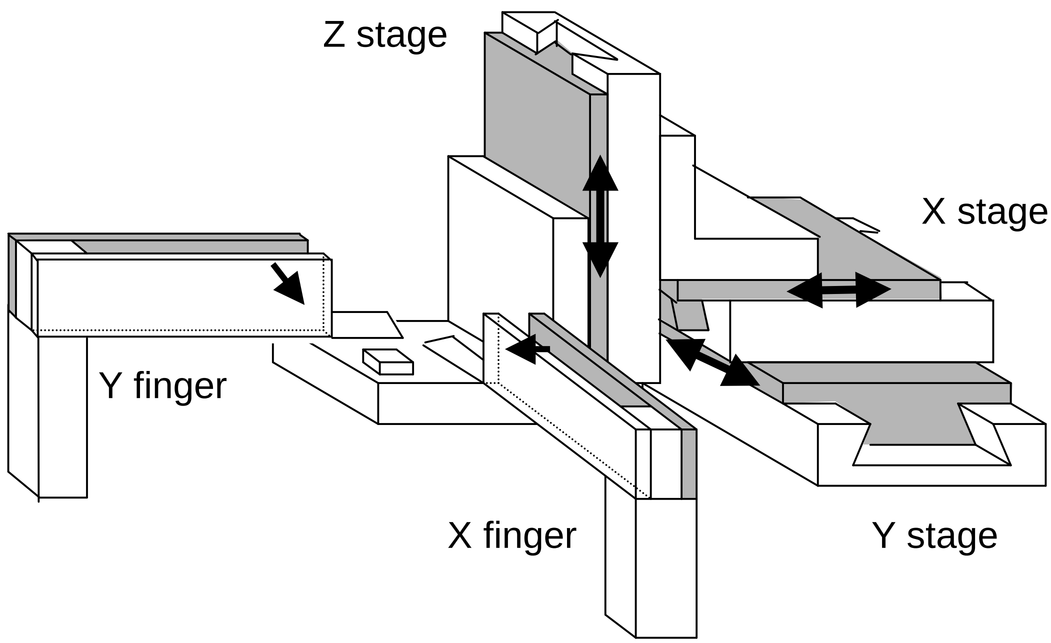


Figure 1: Manipulator configuration

2 Setup outline

2.1 PC control

The PC controls everything. The voltages to the piezoelectric actuator X and Y are controlled by the D/A card outputs. The high-voltage amplifiers magnify the D/A outputs 40 times and apply them to piezoelectric actuators. The strain gauge outputs are amplified by the strain gauge amp 1~4 and read by the multilab card. The multilab card also controls the X, Y and Z stages by TTL signals.

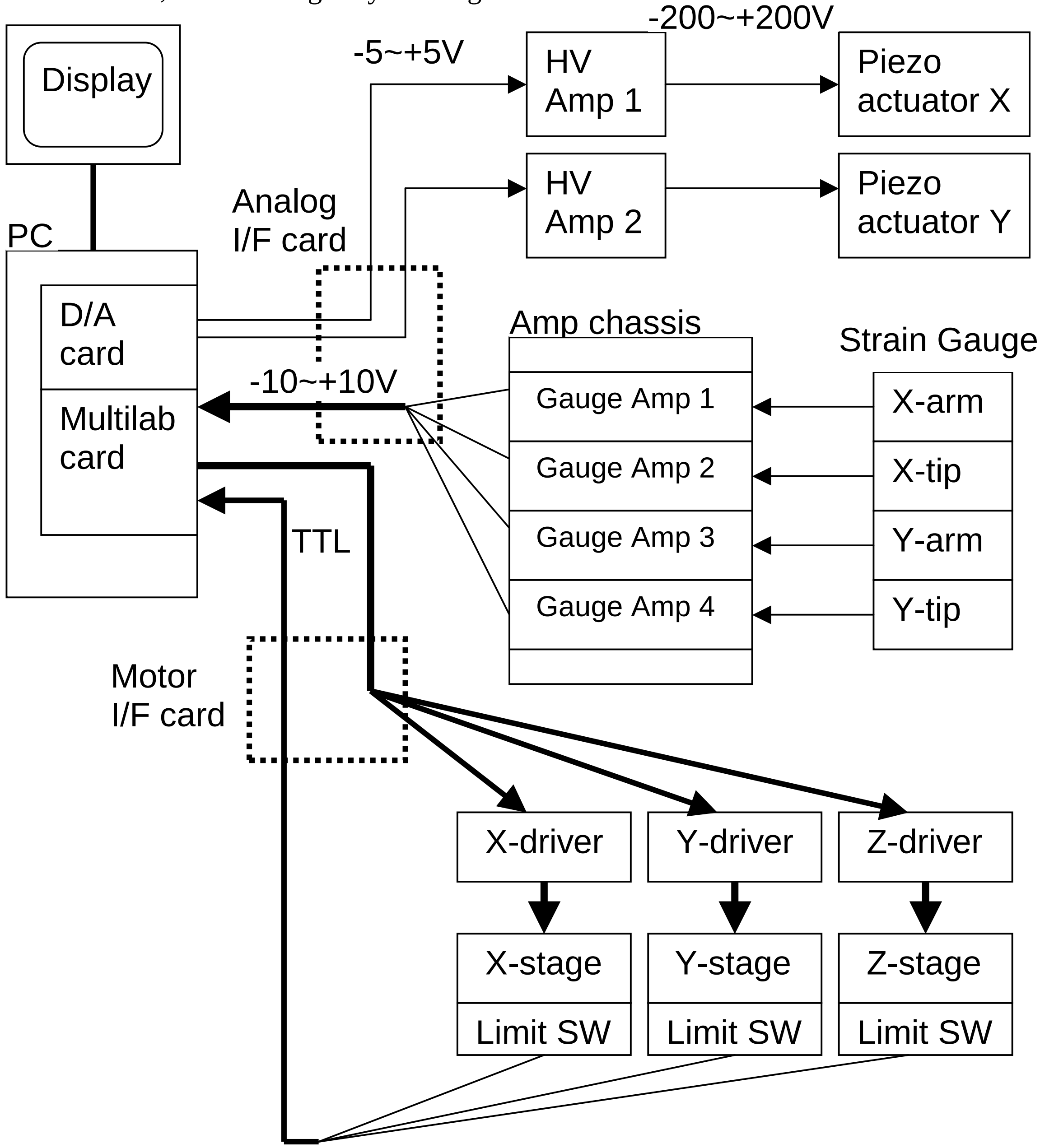


Figure 2: PC control

Table 1: List of PC-controlled equipment

Description	Model	Maker
PC	SP6VS200MT32UC	Intel
Display	V773-1M	Viewsonic Optiquest
Multilab card	PCL-711B	Advantech
D/A card	PCL-726	
High-voltage Amp.1	Model 3211 ($2,950/each)	New Focus
High-voltage Amp.2	790A01	PCB Piezotronics
Amp Chassis	MEPTS-9000	Techkor Instrumentation
Strain gauge Amp.1~4	9000S card ($545/each)	
X,Y,Z-stage	Actuator: 2200-2-AM15245-22 ($1,091)	TS products
	Translation stage:TS433N ($289)	
X,Y,Z motor driver	7006-DB ($145/each)	American Scientific Instrument
Transformer X,Y	XF29	
Transformer Z	XF56 ($20/each)	
Strain gauge	4 ESB-020-350 ($60/matched 4 gauges)	Entran Devices
Piezo actuator X,Y	TH8-R ($76.50/each)	The Face Companies - Thunder

2.2 Monitor

The manipulation is observed through two color cameras. The one is mounted on the stereomicroscope and shows us the top view of the manipulation. The other is attached to the 30-degreee-tilted stand and gives us the side view.

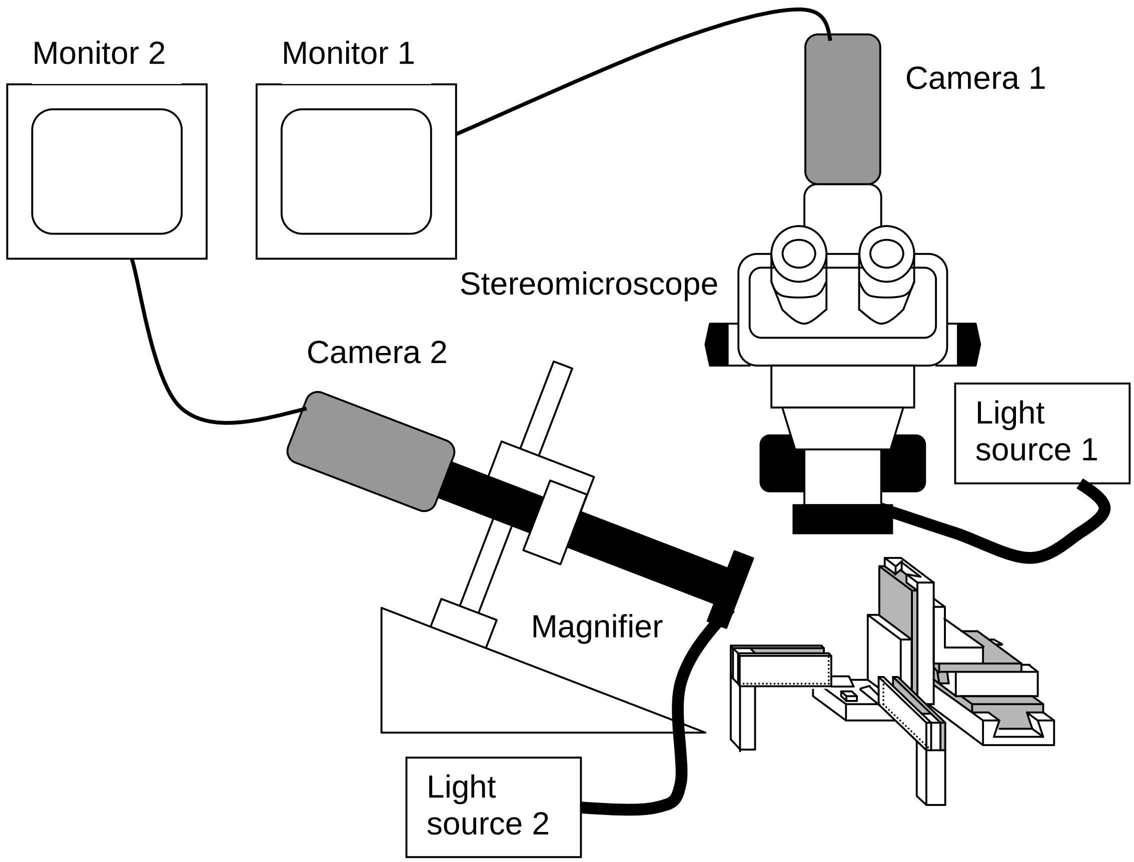


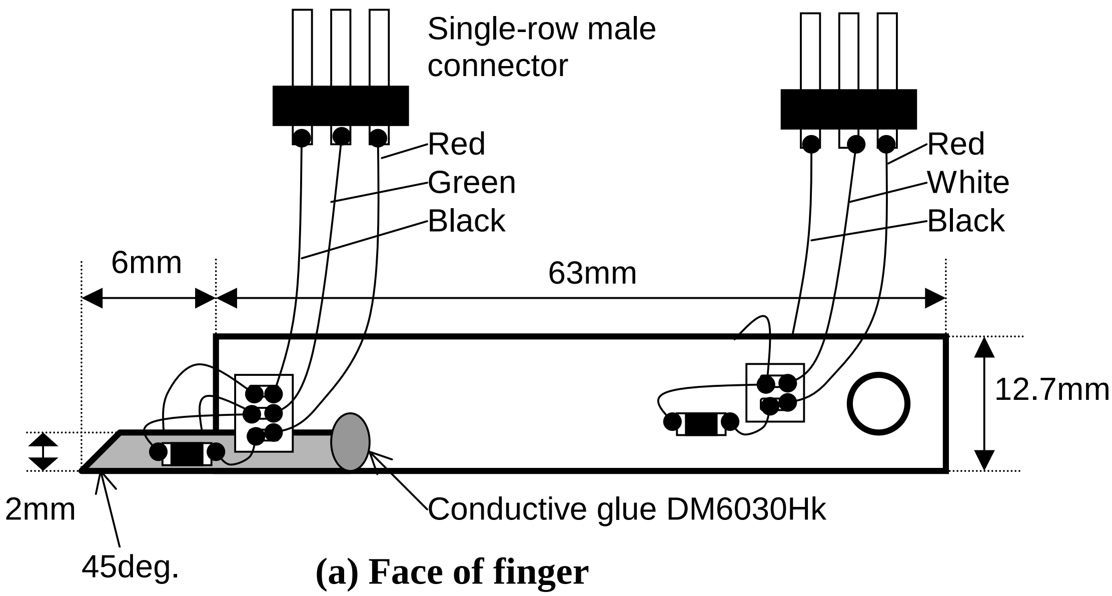
Figure 3: Monitor system

Table 2: List of monitor system

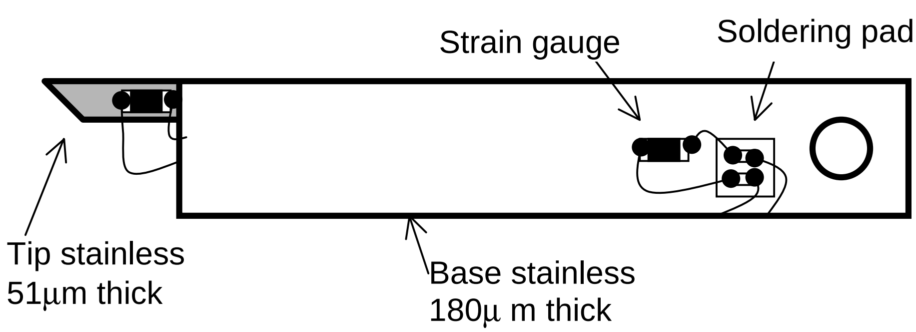
Description	Model	Maker
Monitor 1, 2	PVM-14N2U ($695)	Sony
Camera 1, 2	GP-KR222	Panasonic
Stereomicroscope	SZ6045TRCTV	Olympus
Magnifier	(?)TZM450	Edmund Scientific
Light source 1	Model 180	Dolan-Jenner Industries
Light source 2	Model I-150	CUDA Products

2.3 Tweezers

Each finger consists of the base stainless steel and the tip stainless steel. One couple of strain gauges are attached to the face and the back of the base steel Another couple are attached to the face and the back of the tip steel. All of these strain gauges are Model ESB-020-350 (Entran) and glued by the adhesive of gauging tool and supply kit, ES-TSKIT1 (Entran). The soldering pads in the kit were used to connect their thin gold leads to cables.



(a) Face of finger



(b) Back of finger

Figure 4: Layout of finger

The end of finger is fixed to the stage with piezoelectric actuator, TH8-R (Thunder). The pointed end of screw attached to the actuator pushes and bends the finger. Its deflection can be controlled by the voltage applied to the actuator.

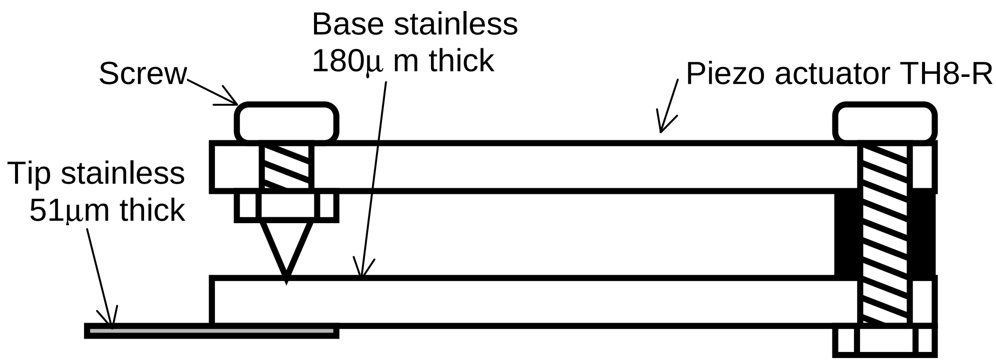


Figure 5: Actuation of finger

3 Setting & connection

3.1 Setting

Table 3: Hardware setting

Hardware	Setting	Meaning
Multilab card PCL-711B	SW1: 1,5=off 2,3,4,6=on	I/O address=220H~22fH
	JP1: -5V selected	D/A range=0~5V
D/A card PCL-726	SW1: 1,4,5=on 2,3=off	I/O address=2c0H~2cfH
	SW1: 7,8=on	Wait state time delay=0
	JP1: Bipolar selected	Bipolar D/A output
	JP2: -5V selected	D/A range=-5~+5V
HV Amp.1 Model 3211	DC offset dial (Offset range=-200~+200V)	DC offset=0V
HV Amp.2 790A01	Gain potentiometer (Voltage gain range=5~50V/V)	Gain = 40 V/V
Strain gauge Amp.1~4 9000S card	S3: 1,4=off 2,3=on	Constant voltage excitation
	S1: 1,3,4,5,8,9=off 2,6,7,10=on S2: 1,3,4,7,9,10=off 2,5,6,8=on	Half Bride configuration with $A_{tension}$ and $B_{tension}$ calibration shunt
	Voltage adjustment trim-pot	Voltage exitation=1.25V
X,Y motor driver 7006-DB	J1: installed	Idle mode = on
	J2: open J3: upper installed J4: upper installed	Controlled through CN1 (On-Board oscillator isn't used)
	JP5: upper installed Oscillator SW: only 4 = on	Frequency=1111Hz
	Motor current SW: 0.25A,Reset=off The others=on	Motor current = 0.25A
	Mode dip SW: All=off	-Half step mode -High speed decay mode - Disable = off
Z motor driver 7006-DB (new)	J1: installed	Idle mode = on
	J2&J3: installed	External 5V is not provided
	Motor current SW: 0.25A,Reset=off The others=on	Motor current = 0.25A
	Mode dip SW: All=off	-Half step mode -High speed decay mode - Disable = off

3.2 Connection

3.2.1 Analog

3.2.1.1 Outline

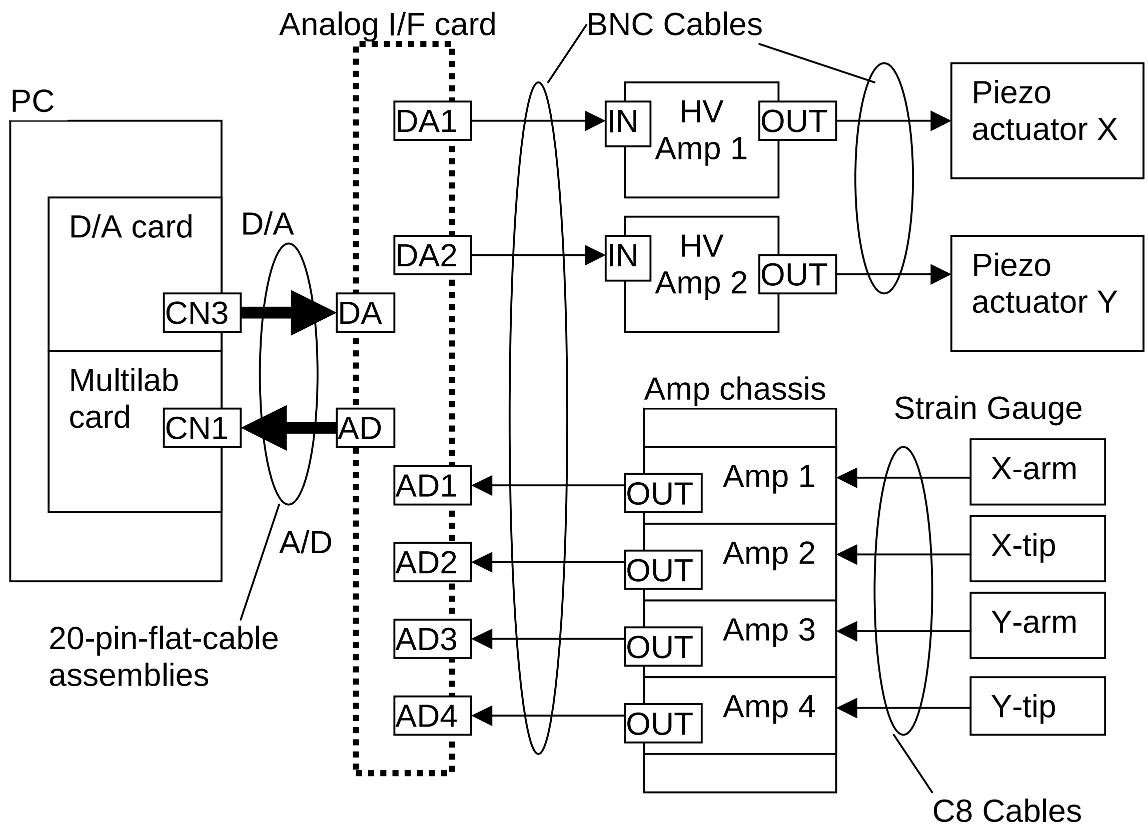


Figure 6: Analog connection scheme

3.2.1.2 Analog I/F card

The analog I/F card is used to connect six BNC-cables and two 20-pin-flat-cables. It doesn't have any circuits.

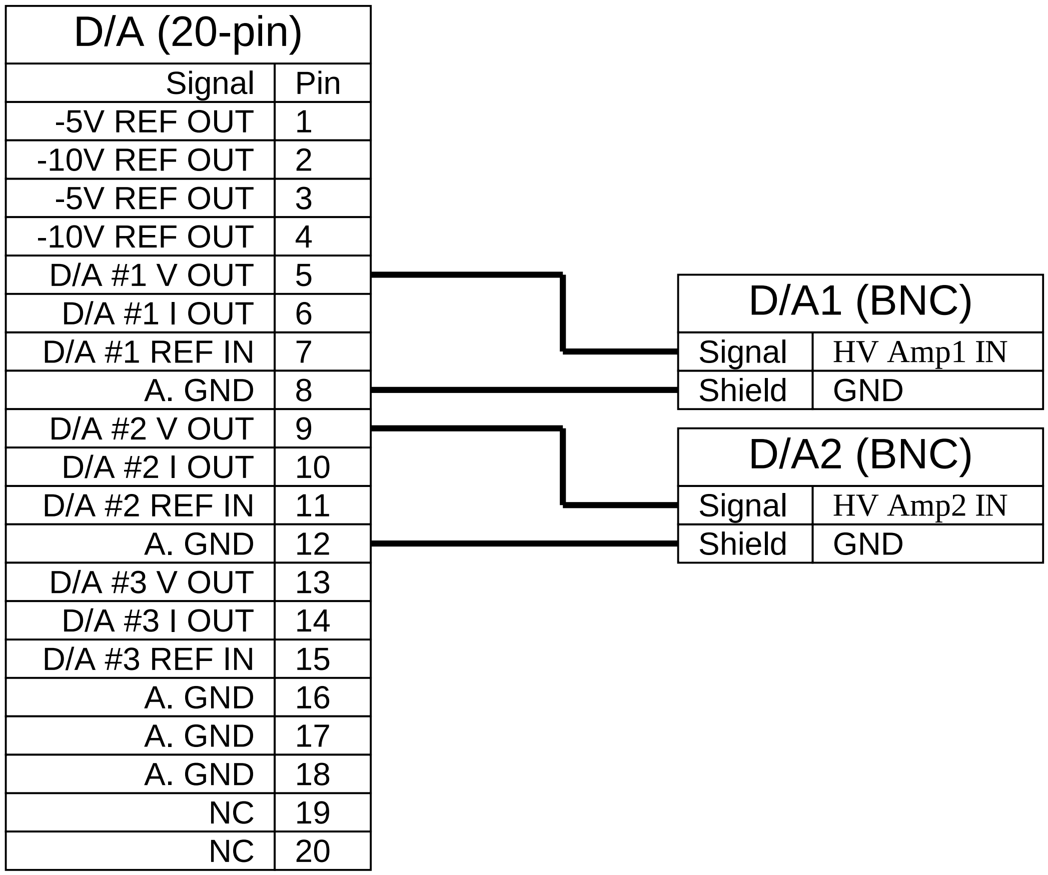


Figure 7: Analog I/F card (1/2)

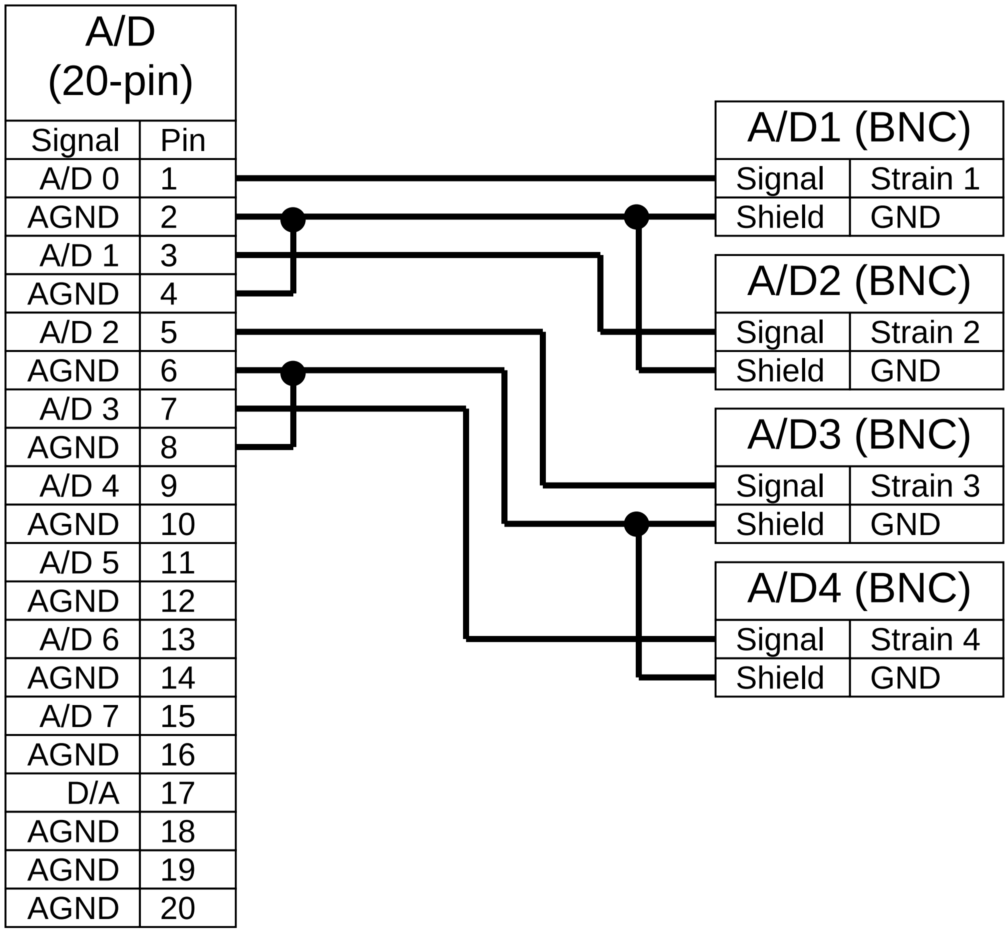


Figure 8: Analog I/F card (2/2)

3.2.1.3 Strain gauges connection

C8 cable ($48) of Techkor Instrumentation is 25 feet of rugged shielded cable with 8-pin-connector. A 3-pin-famale connector is attached to the other end of the cable in order to connect a couple of strain gauges.

C8 cable(8-pin)		
Pin	Signal	Color
1	Active Shield	Shield
2	Negative Excitation	Black
3	Positive Excitation	Red
4	Negative Input Sig.	White
5	Positive Input Sig.	Green
6	Top of Bridge	Yellow
7	Middle of Bridge	Orange
8	Bottom of Bridge	Blue

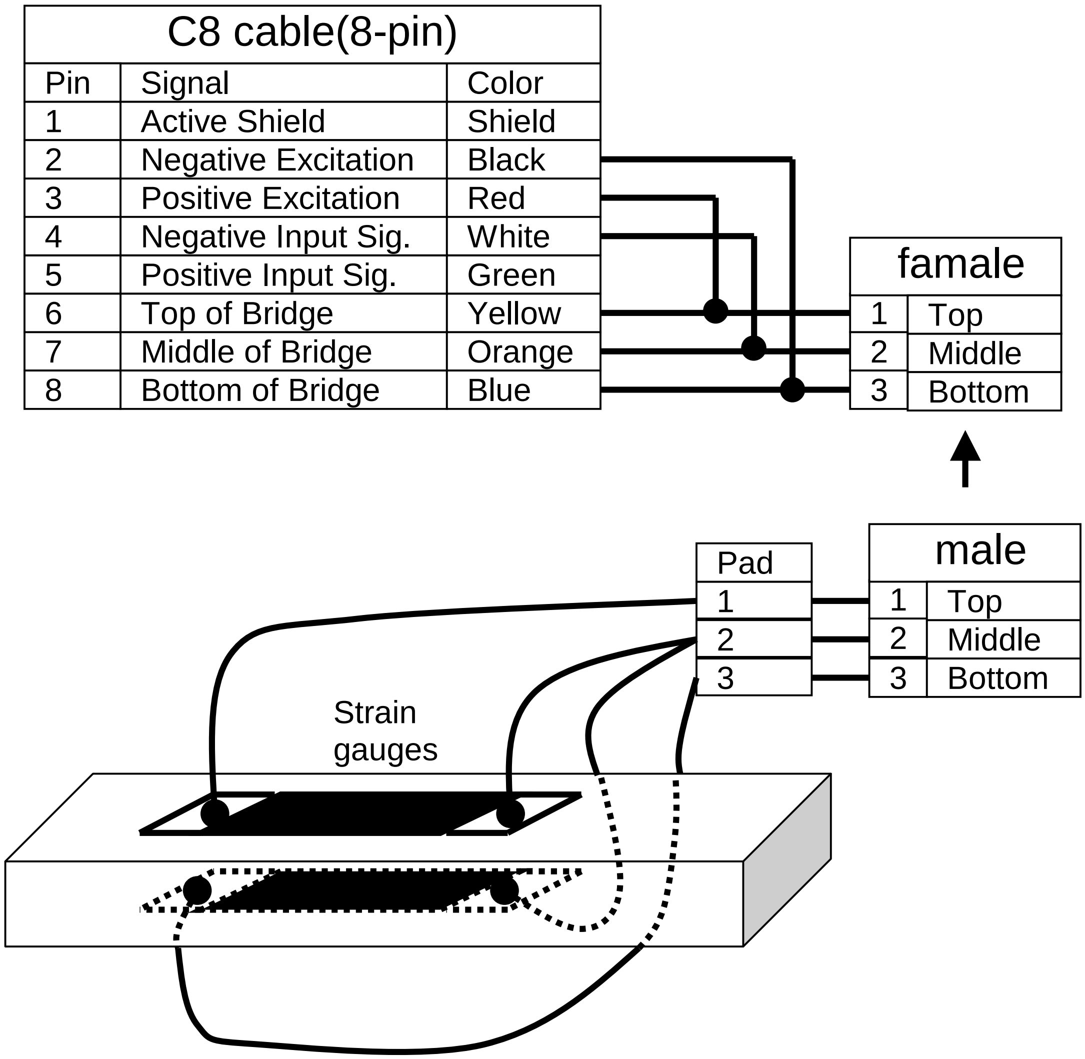


Figure 9: Strain gauges connection

3.2.2 Digital

3.2.2.1 Outline

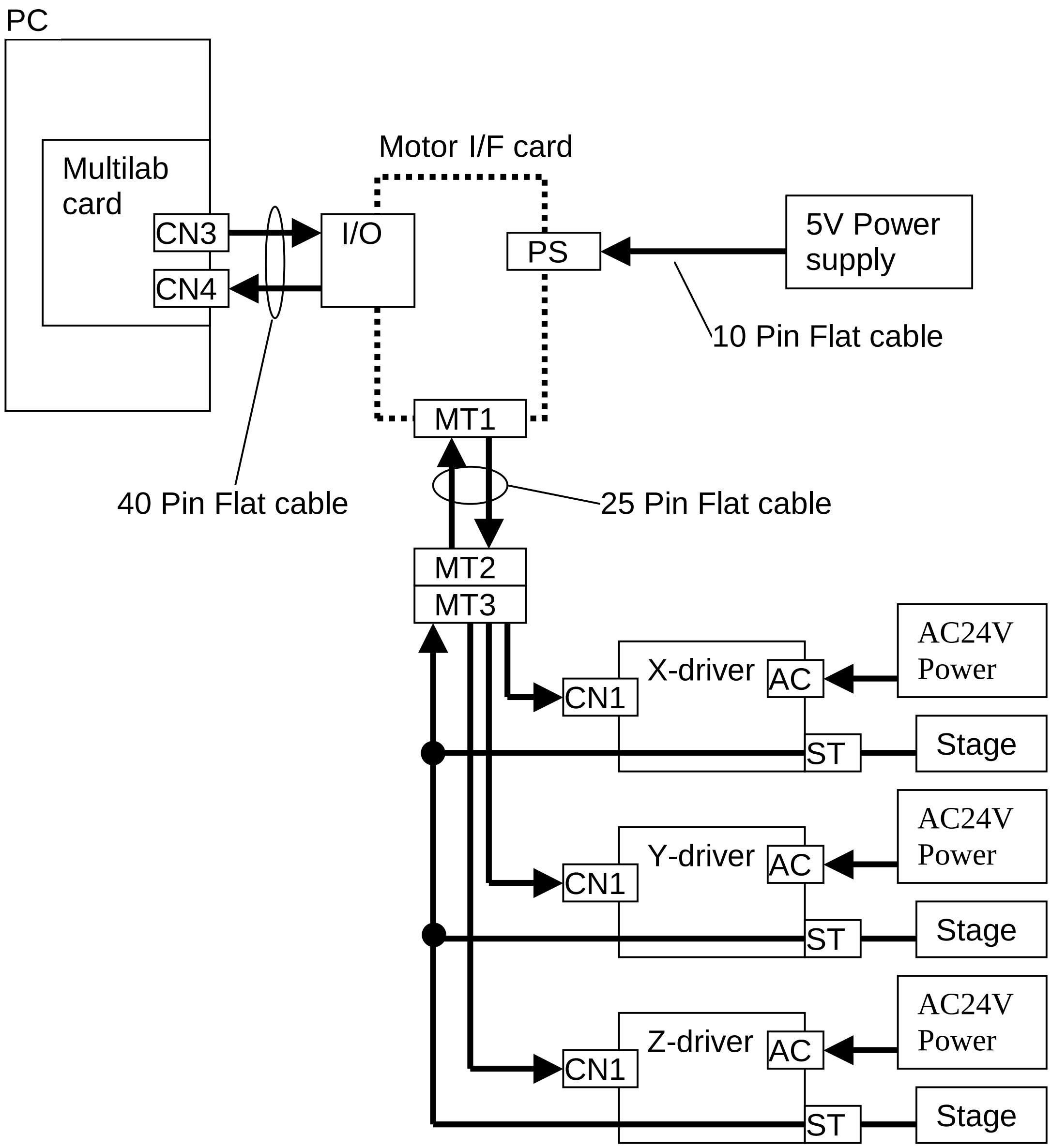


Figure 10: Digital connection scheme

3.2.2.2 Motor I/F card

The motor I/F card provides a hardware interlock to prevent stages from overrunning their limits. While it detects a limit input, it simply bans the output of clock signal to the driver and turns on the indicator LED. By changing the switch position on the card, you can lift the ban. After moving the stage to the normal range, please don't forget to change the switch position for the interlock.

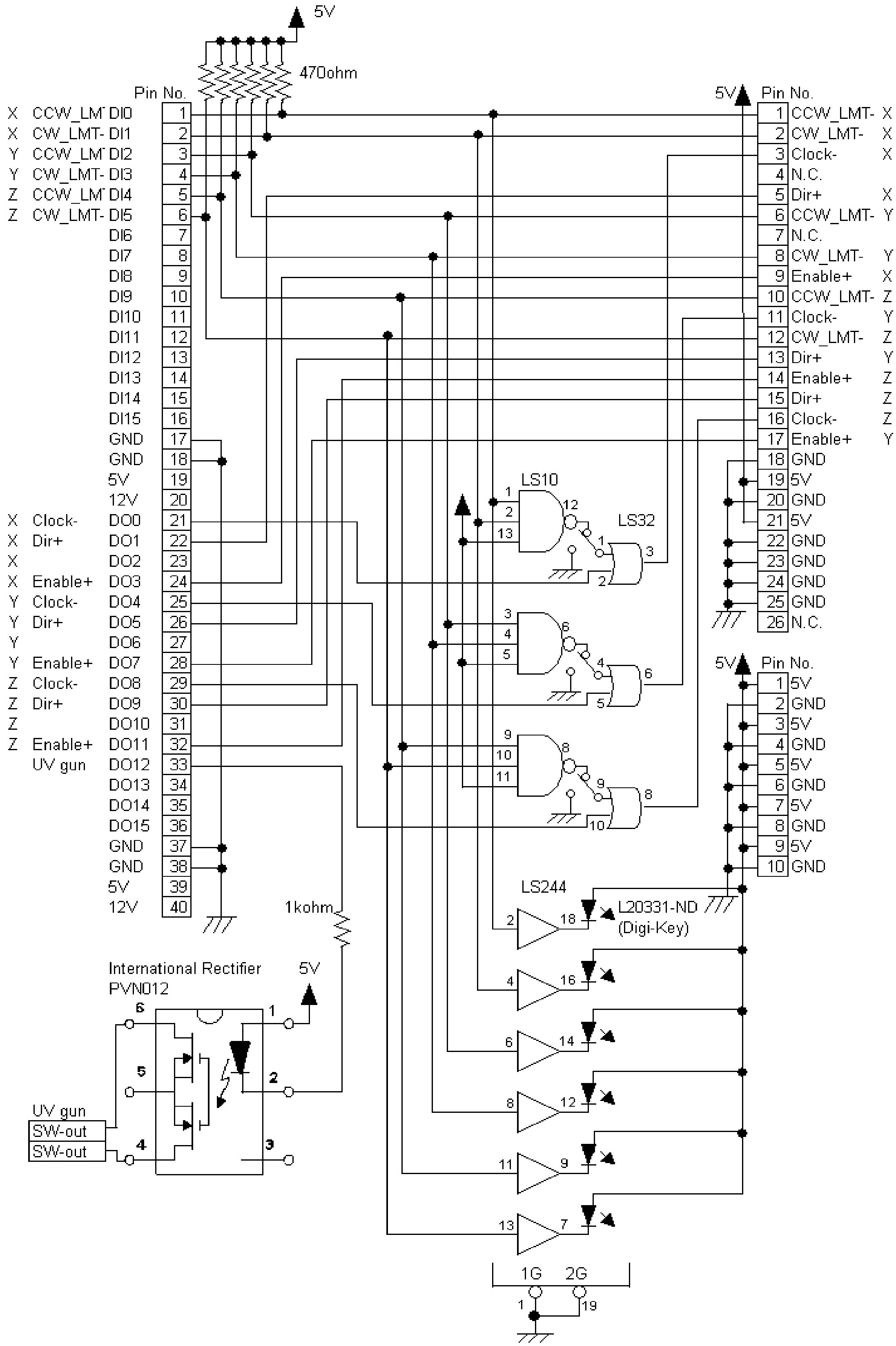


Figure 11: Motor I/F card

3.2.2.3 Driver connection

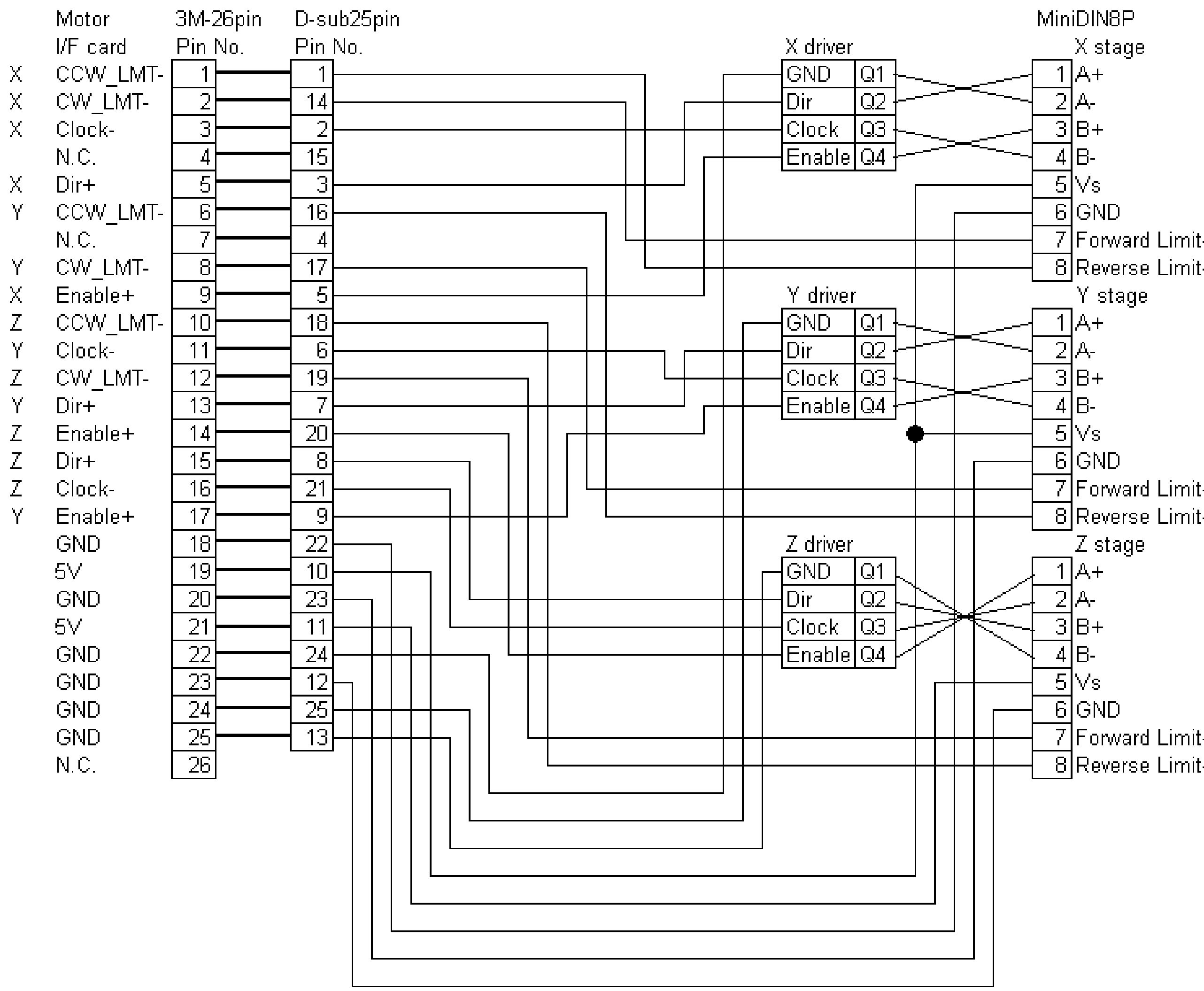


Figure 12: Driver connection

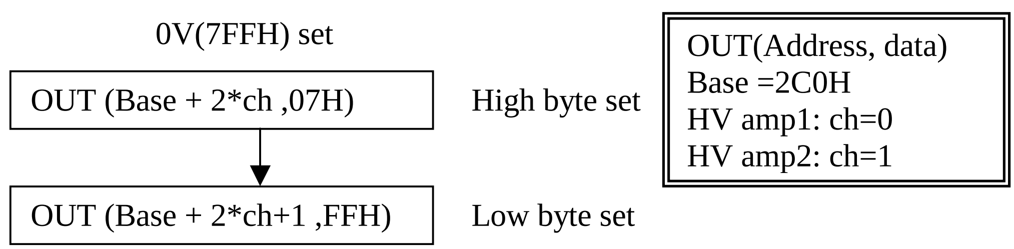
4 Software interface

4.1 Piezo actuator control

The high-voltage amplifiers magnify the D/A outputs 40 times and apply them to piezoelectric actuators. The high-voltage amp1 (Model 3211) doesn't invert the signal while the high-voltage amp2 (790A01) inverts the signal.

Table 4: Piezo voltage

12bits data	D/A output	HV amp1 output	HV amp2 output
000H	-5V	-200V	+200V
7FFH	0V	0V	0V
FFFH	+5V	+200	-200



Note: the high byte should be set before the low byte.

Figure 13: D/A set procedure

4.2 Strain read

While the output range of strain gauge amplifier is –10~+10V, the input range of Multilab card is –5V~ +5V. Because the overvoltage of the card is +/-30V max., the card won't be damaged by the output of strain gauge amplifier. But it can't read a voltage over +/-5V.

Table 5: A/D convert

A/D input	Digital 12 bit data
-5V	000H
0V	7FFH
+5V	FFFH

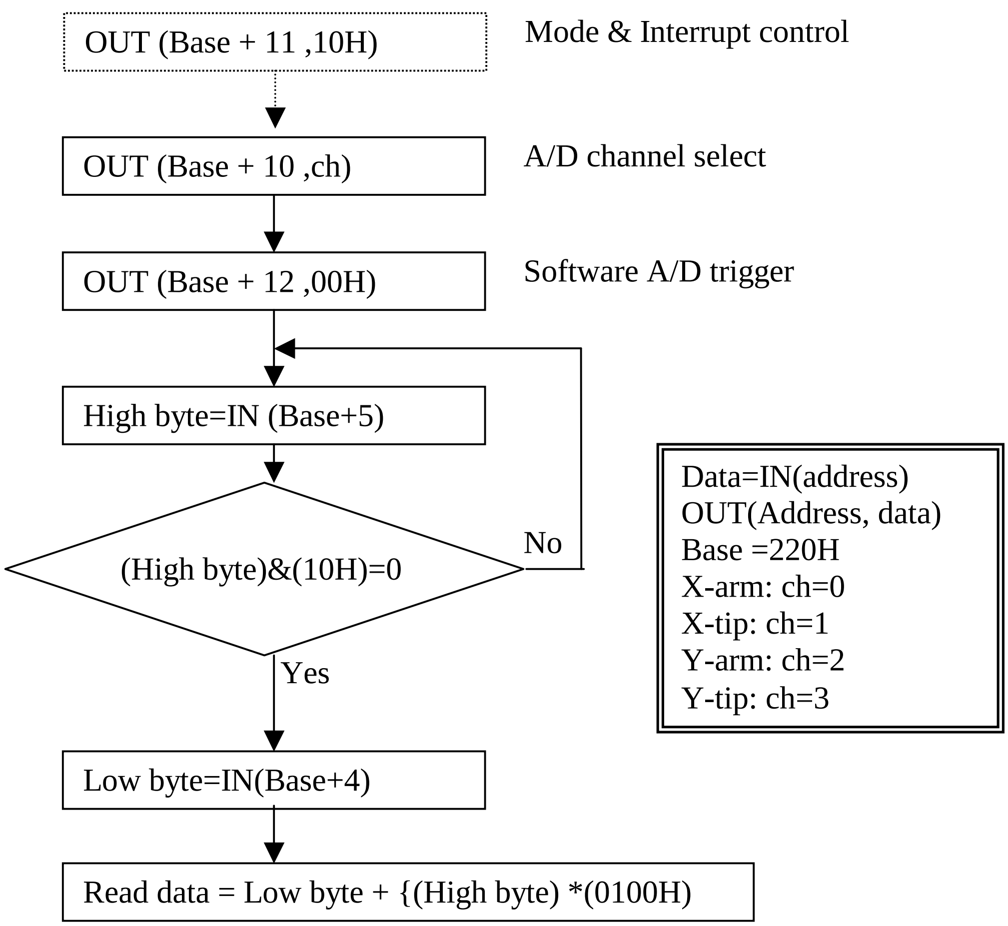


Figure 14: A/D convert procedure

4.3 Motor control

The signal “Enable+” should be kept 1. Otherwise the motor won’t be energized. To move the stage, select the direction of rotation by “Dir+” and send negative pulses as “Clock-”. The Visual Basic software by Eiji uses about 440Hz as the maximum clock in all directions. It keeps the same rate from the start to the end. If higher speed is necessary, the trapezoidal rate control will be needed.

Table 6: Motor control I/O

Address	Bit	No	Axis	Singnal	Note
IN Base+6	0	DI0	X	CCW_Limit-	Limit-: 1(normal) / 0(over limit)
	1	DI1	X	CW_Limit-	
	2	DI2	Y	CCW_Limit-	
	3	DI3	Y	CW_Limit-	
	4	DI4	Z	CCW_Limit-	
	5	DI5	Z	CW_Limit-	
	6	DI6			
	7	DI7			
IN Base+7	0	DI8			
	1	DI9			
	2	DI10			
	3	DI11			
	4	DI12			
	5	DI13			
	6	DI14			
	7	DI15			
OUT Base+13	0	DO0	X	Clock-	Enable+: 1(energize) / 0(de-energize) Dir+: 1(CW) / 0(CCW) Clock-: 1(normal) / 1pulse (1 step)
	1	DO1	X	Dir+	
	2	DO2	X		
	3	DO3	X	Enable+	
	4	DO4	Y	Clock-	
	5	DO5	Y	Dir+	
	6	DO6	Y		
	7	DO7	Y	Enable+	
OUT Base+14	0	DO8	Z	Clock-	
	1	DO9	Z	Dir+	
	2	DO10	Z		
	3	DO11	Z	Enable+	
	4	DO12	UV	UV gun	1(Normal)/1pulse(Toggle ON/OFF)
	5	DO13			
	6	DO14			
	7	DO15			

Note: Base=220H CW: stage-expanding direction CCW: stage-contracting direction

5 Calibration

5.1 Initialization

I usually did zero-dial-adjustment of strain gauge amps after the voltage process (0V→200V→0V) was applied to the piezoelectric actuators. Otherwise I couldn't figure out the origin of the deflection due to the hysteresis of actuators.

5.2 Deflection and force

The strain gauge outputs can be converted into deflection or force. I measured the conversion factors in the experiments. The total deflection can be calculated by the following equation. As for the details, please refer to the document, "Calculations about dexterous tweezers".

$$\text{(Total deflection)} = -(C_a K_a) V_a + (1+0.2)(C_t K_t) V_t \qquad \text{eq.(1)}$$

V_a: arm strain gauge amp. output
Vt: tip strain gauge amp. output

Table 7: conversion factors

	Conversion factor	Right arm	Left arm
C_aK_a	(Total deflection)/(Arm gauge amp. output) When (Tip gauge amp. output)=0V.	224(micron/V)	210(micron/V)
C_tK_t	(Tip deflection)/(Tip gauge amp. output)	10.5(micron/V)	12.6(micron/V)
F_3/V_t	(Force)/(Tip gauge amp. output)	0.901(mN/V)	1.09(mN/V)

5.3 Strain gauge

5.3.1 Calibration and strain range

I define R_g as the strain gauge resistance and R_1 as the balanced resistances in 9000S strain gauge amplifier. Since a couple of strain gauges are attached to the opposite side of beam, these resistances change in the opposite directions when it is bent.

When I define ε as the strain of beam surface and ΔR_g as the resistance change by the strain, $\Delta R_g/R_g$=(Gage Factor)ε. In Figure 15, the output voltage, V_{out}, can be calculated as follows:

$V_{out}=K(V_1-V_2)=K\{1/2-(R_g-\Delta R_g)/(2R_g)\}V_{ex}$

$=KV_{ex}\Delta R_g/(2R_g)$ $(\leftarrow \Delta R_g/R_g=(\text{Gage Factor})\varepsilon)$

$= KV_{ex}(\text{Gage Factor})\varepsilon/2.$ ________________ eq.(2)

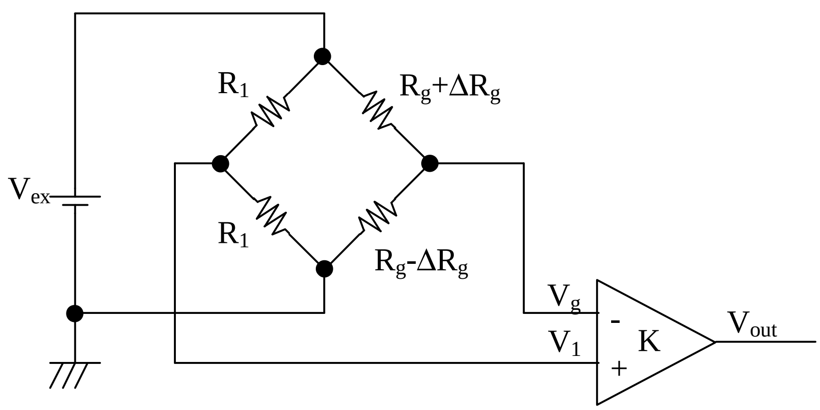


Figure 15: strain-voltage convert

Figure 16 shows the schematic at the shunt calibration of 9000S strain gauge amplifier. The output voltage at the shunt is calculated as follows:

$R_{g2}=1/(1/R_g+1/R_s) = R_g(1+R_g/R_s)^{-1}=R_g(1-R_g/R_s)$ $(\leftarrow R_g \ll R_s)$

$V_{out}= K(V_1-V_2)=K\{1/2-(R_{g2})/(R_g+R_{g2})\}V_{ex}$

$= KV_{ex} R_g/(4R_s-2R_g)$ ____________________ eq.(3)

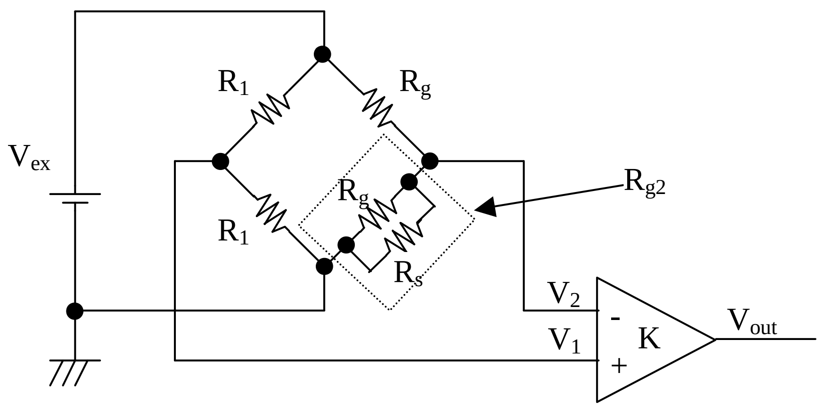


Figure 16: shunt calibration

By comparing eq.(2) and eq.(3), eq.(4) is obtained.

(Gage Factor)$\varepsilon/2= R_g/(4R_s-2R_g)$________________eq.(4)

When I apply the following actual value to eq.(4), I can get the simulated strain, ε, by the shunt.

(Gage Factor)=+155
$R_g=350\Omega$
$R_s=49.9k\Omega$
$\varepsilon= R_g/(2R_s-R_g)$/(Gage Factor)=350/(2*49.9k-350)/155=$2.27*10^{-5}$=22.7µ strain

The recommended strain level by the maker is 0-1000µ strain. I usually set the gain level of strain gauge amplifier so that “Shunt A(49.9kΩ) makes 1V output increase. So 1V stands for 22.7µ strain. The output voltage ranges from –10V(=-227µ strain) to +10V(=227µ strain). But there is possibility that the strain might exceed 1000 µ strain on the arm strain gauges. Because the arms are pre-bent by the actuators.

By applying Vout=1V, ε=22.7µ, (Gage Factor)=+155 and V_{ex}=1.25V to eq.(2), the OP-amp gain K is obtained. K is about 455(V/V).

5.3.2 Alteration of card and cable

I personally analyzed the circuit of the strain gauge amp as shown in Figure 17 and Figure 18, because I had trouble with its connection. I used 4 amp cards. I purchased one of them during my stay. The others were maybe bought by the previous researchers. I have altered the pin assignment of old cards and the color assignment of old cables so that they are all compliant to the manual.

Table 8 and Table 9 show the altered points in old cards and cables. Aside from the alteration, I also changed two resistances in the new card ("D",Sn.01590) as shown in Table 10. This change was done in order to expand the zero offset adjustment range.

Table 8: cable color before alteration

Pin of C1 connector	Old cables labeled "A","B"	New cables labeled "C","D"	Manual
1	→	→	Shield
2	→	→	Black
3	→	→	Red
4	Green	→	White
5	White	→	Green
6	→	→	Yellow
7	→	→	Orange
8	→	→	Blue

Table 9: pin assignment before alteration

Pin of C1 connector	Old cards "A": Sn.01366 "B": Sn.01367 "C": Sn.01368	New card "D: Sn.01590	Manual "MEPTS-9000" Revision G.4
1	→	→	Active shield
2	(+)Input	→	(-)Excitation
3	(-)Input	→	(+)Excitation
4	(+)Excitation	→	(-)Input
5	(-)Excitation	→	(+)Input
6	Bottom of bridge	→	Top of bridge
7	→	→	Middle of bridge
8	Top of bridge	→	Bottom of bridge

Table 10: change of resistance in the new card

Resistance on daughter board in 9000S card	Old cards "A": Sn.01366 "B": Sn.01367 "C": Sn.01368	New card "D: Sn.01590	
		Original state	Current state
R3	2.49kΩ	7.9kΩ	2.49kΩ
R10	24.9Ω	10Ω	24Ω

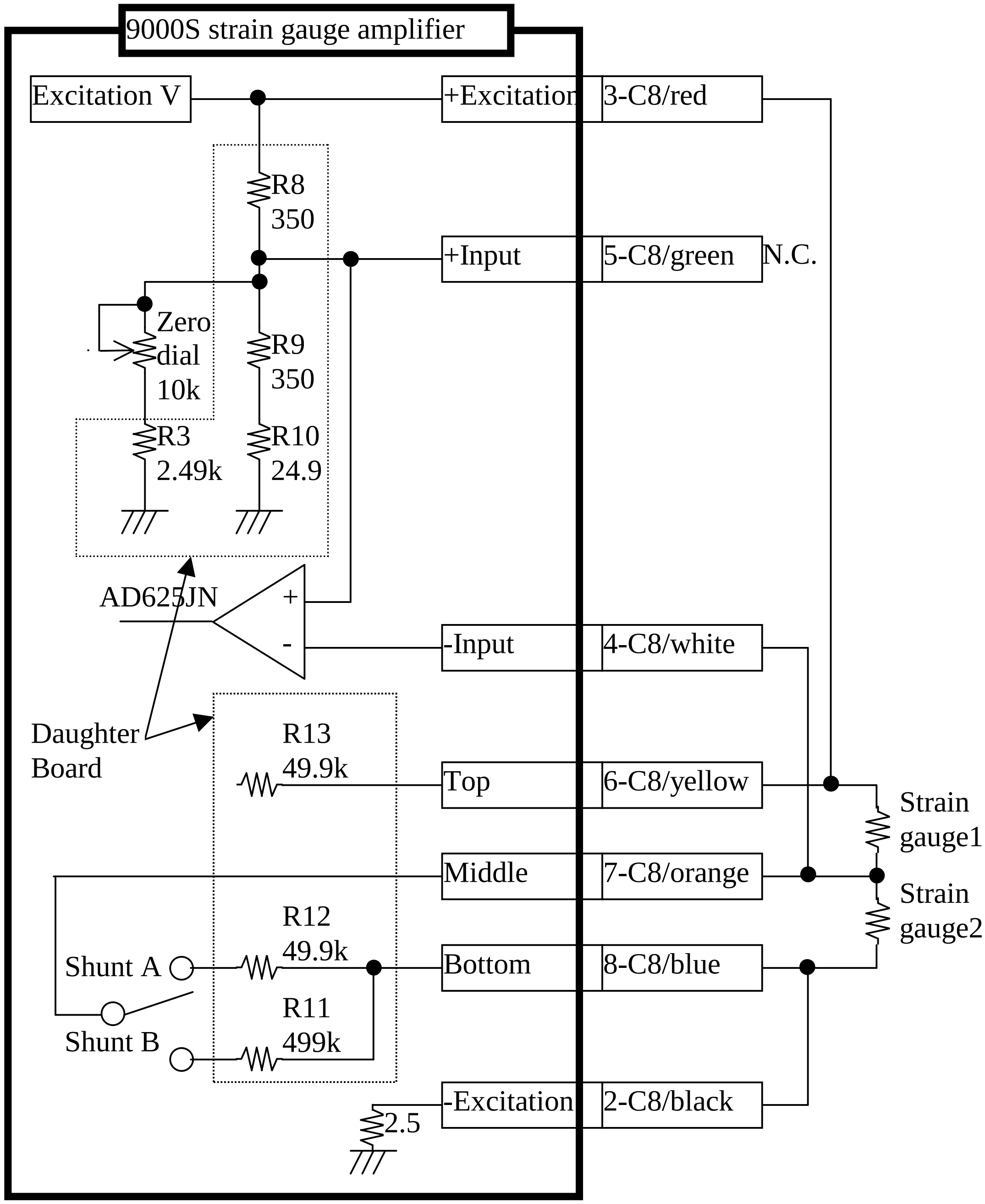


Figure 17: the connection schematic of 9000S card

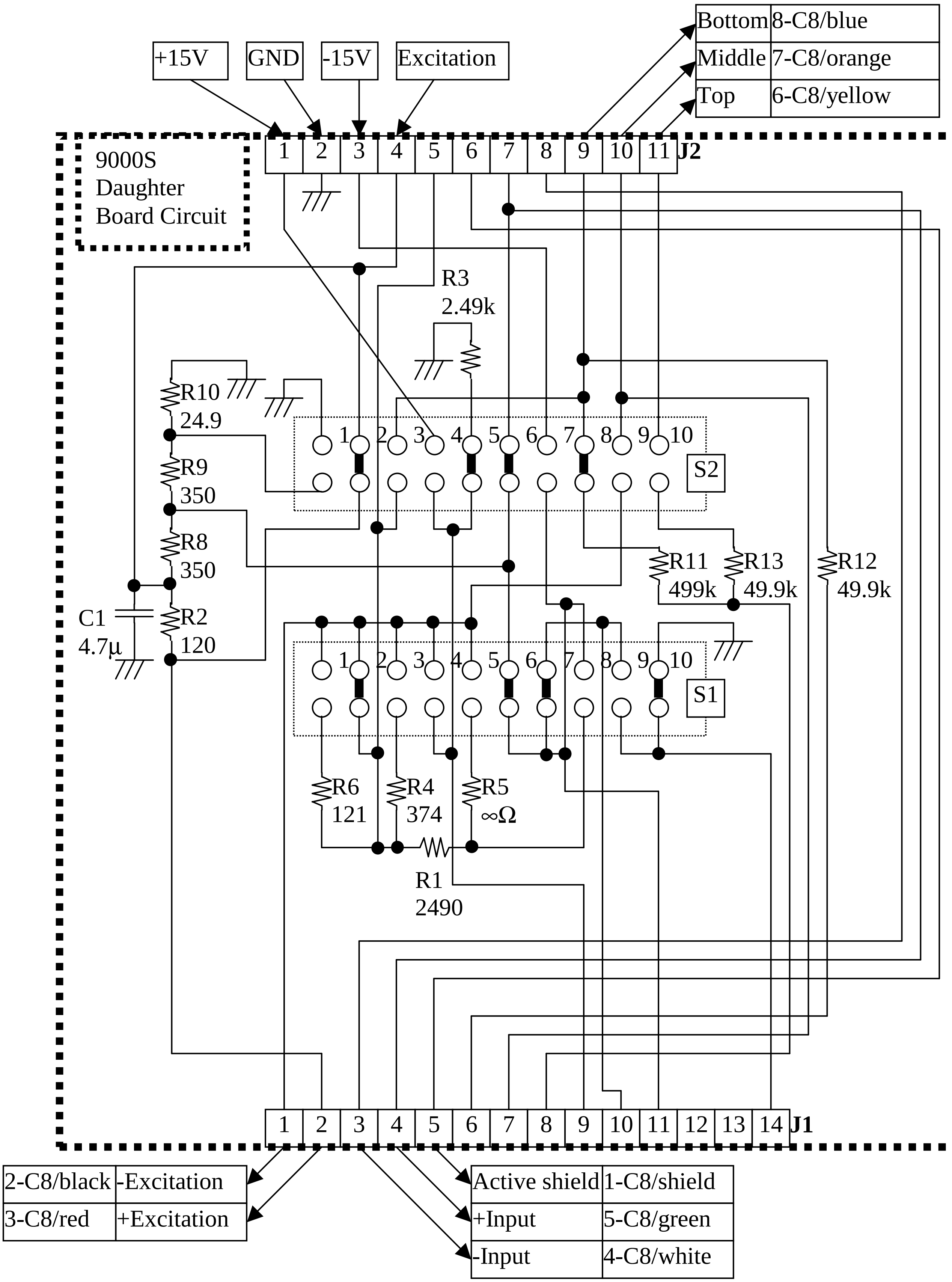


Figure 18: circuit of daughter board in 9000S card