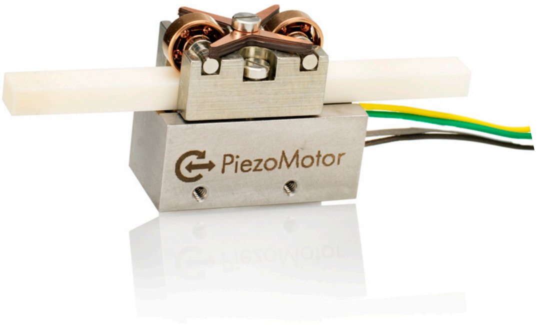
Piezo LEGS® Linear 6N



- **Direct Drive - Backlash Free Motion**
- **Nanometer Resolution**
- **Simple Drive Electronics**
- **No power draw in hold position**

The Piezo LEGS® 6N linear motor is intended for a very large range of applications. The motor is ideally suited for move and hold applications or for automatic adjustments. This is due to the fact that the motor does not require any power in hold position as well as that the motor has no backlash and can move in increments of single nanometers. The motor is operating in a non-resonant mode and is not sensitive to different cable lengths etc.

The maximum force of the motor is set by the number of springs giving the force. The standard motor is set for a stall force of 6.5N. Higher forces are optional (up to 10 N).

The Piezo LEGS® 6N linear motor is available in different versions for vacuum and non-magnetic environments. The motor is easily integrated and the drive rod can also be equipped with an adapter (optional) to further facilitate the mechanical integration in many systems.

There are now possibilities for other lenths of drive rods as standard (30, 40, 50, 60, 70 and 101.8 mm). See next page for item no. Special length can be made on requets.

Operating modes

The motor can move in full steps, shorter steps or partial steps (micro-stepping) giving positioning resolution in the nanometer range. For extreme positioning requirements in the sub-nanometer range a bending mode is possible. Speed is easily adjustable from extremely low up to max specified.

Controlling the motor

PiezoMotor offers a range of drivers and controllers. The basic one is a handheld push button driver. An option is the PDA 3.1 analouge driver that regulate the motor speed by means of an analogue ±7 Volt interface. The more advanced alternative is the PMD90 microstepping driver/controller. This product enables the user to vary the waveforms as well as speed. There is also a connector for a quadrature encoder signal. The microstepping feature divides full step cycle in up to 2048 increments which results in steps as small as two nanometers. More information is available upon request.

PDA 3.1

PMD90

Design your own driver

Most customers prefer to design their own driver control for ease of integration. In this case PiezoMotor will provide all relavant information for a successful design.

Ordering Information

LL1011A-	Stainless Steel
LL1011C-	Non-Magnetic
LL1011D-	Non-Magnetic, Vacuum

Drivers and Controllers

PMCM21-01	Handheld driver
PMCM31-01	PiezoMotor Driver Model PDA 3.1
PMD90	Microstepping Driver

Accessories

ECA-PMD031-00	Motor cable

PIEZO LEGS DRIVE PRINCIPLE

This section describes in detail the drive principle for Piezo LEGS linear motors.

Drive leg

The Piezo LEGS motor consists of a number of piezoceramic drive legs. The number of legs depends on the motor configuration. A drive leg can be considered as a piezoceramic bimorph. In principle, a bimorph can be described as two piezoelectric layers with one intermediate and two external electrodes electrically separated from each other. In this way, it is possible to activate each layer independently of the other by an electric voltage.

Figure 1 shows the two modes of motion, extension/contraction and bending, for a drive leg. In Fig. 1a, no voltage is applied to the drive leg. In Fig. 1b, a voltage is applied to the leg's right side. Due to the applied voltage (shaded blue), the right side will expand and cause the whole drive leg to bend to the left. Fig. 1c shows equal voltages applied to both sides. Compared with Fig. 1a, the drive leg has now made a linear expansion. Finally, Fig. 1d shows the opposite effect to that seen in Fig. 1b.

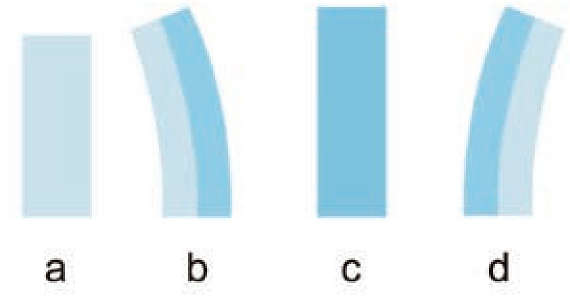
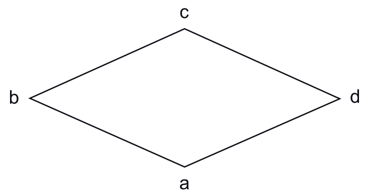


Fig. 1. The two modes of motion, extension/contraction and bending, of a drive leg. The blue shaded parts illustrate an applied voltage.

The tip of the drive leg can move arbitrarily within a certain area if no load is present. For an ideal bimorph and for small strokes, this area constitutes a rhomb. Fig. 2 shows the position for the tip of the leg with voltages applied as in Figs. 1a to d.

Fig. 2. The rhombic area within which the tip of the drive leg can move arbitrarily.



The bending x and extension/contraction z of a drive element can be written as:

$$x(t)= k_1 \left[u_1(t)-u_2(t)\right]$$
$$z(t)= k_2 \left[u_1(t)+u_2(t)\right] \qquad (1)$$

where k_1 and k_2 are constants depending on material, geometry, drive conditions, etc. If phase-shifted repetitive voltage signals are applied to the respective side of the drive leg, the tip of the drive leg will move along a certain trajectory within the allowed motion area. As an example, drive voltages u_1 and u_2 are applied to the drive leg according to Fig. 3. In Fig. 3a, the tip will traverse the sides of the rhombic area. In Fig. 3b, the drive voltages are phase-shifted sinusoidal voltages, which give an elliptical trajectory. The phase shift affects the geometry of the trajectory, in this case, the lengths of the major and minor axis. The optimum phase shift depends on drive conditions, geometry, material of the leg, etc., and has to be adapted for each individual application.

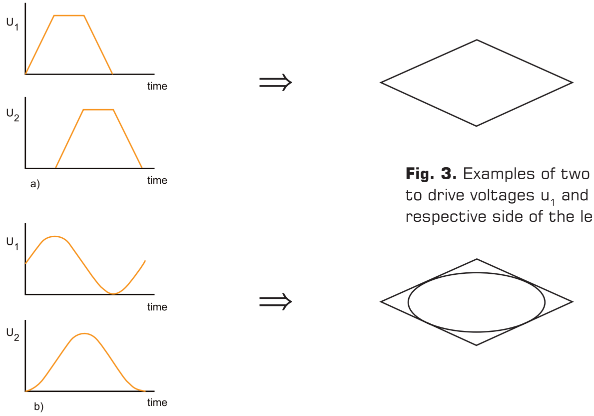
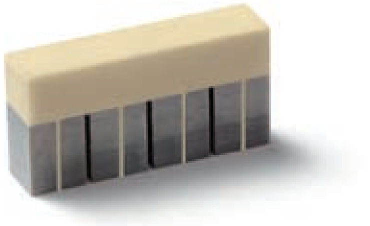


Fig. 3. Examples of two trajectories due to drive voltages u_1 and u_2 applied to the respective side of the leg.

The walking drive principle

The utilized drive principle of the motor is a non-dynamic type, i.e. the position of the drive legs is known at every given moment. Fig. 4 describes the walking principle. A darker blue shade at a side of a drive leg represents a higher applied voltage. Consider a motor element as two pairs of drive legs that operate independently. Imagine that drive legs a and c are the drive legs of the first pair. These legs work synchronously. Similarly, drive legs b and d belongs to a second pair and also work synchronously. The sequences shown at right, when repeatedly cycled, results in a transportation of the moving object.

Four characteristic sequences of motion are easily distinguished. In Fig. 4a, the drive legs of the first pair are in their gripping sequence. The moving sequence takes place from Figs. 4a to 4d. In Fig. 4d the drive legs of the first pair are in their releasing sequence. Eventually the return sequence takes place from Figs. 4d to 4a. In theory, the gripping and releasing sequences could be almost indefinitely short, but in reality, gripping and releasing take place during a certain time period.



A motor element consists of a number of drive legs.

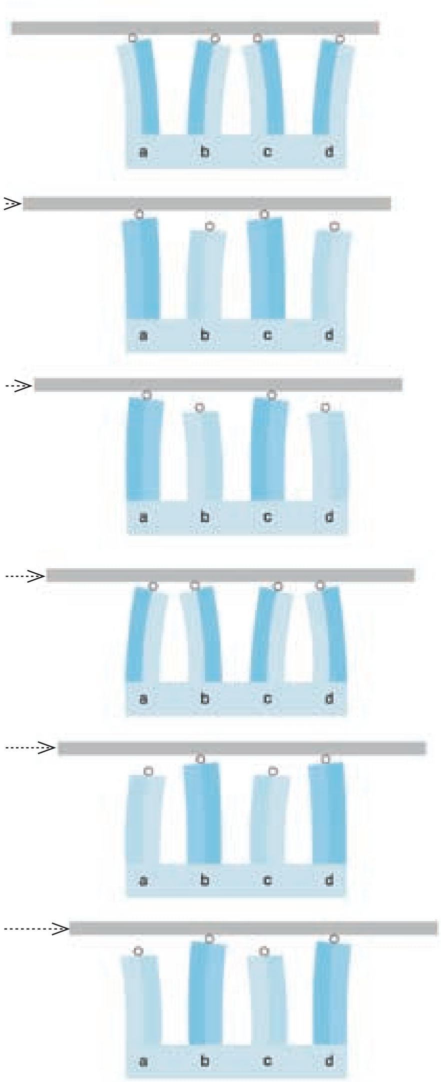


Fig. 4. Schematic illustration of the walking drive principle.

a A drive cycle starts with both pairs of drive legs in contact with the drive rod. The legs of the first pair (a and c) are bent to the left and the legs of the second pair (b and d) are bent to the right.

b The legs of the first pair move in an upper right direction. In contrast, the legs of the second pair move in a lower left direction. This means that the drive legs of the second pair will loose contact with the drive rod, and that the drive rod will follow the motion of the drive legs of the first pair.

c After some time the drive legs have changed their motion. The drive legs of the first pair will now move in a lower right direction and the drive legs of the second pair will move in a upper left direction.

d The change of motion of the two pairs of legs means that the second pair will come in contact with the drive rod again but now at a slightly different position.

e The legs of the second pair (b and d) now move in an upper right direction, while the legs of the first pair (a and c) move in a lower left direction. The result is that the drive legs of the first pair loose contact with the drive rod, which follows the motion of the second pair.

f After some time the drive legs have changed their motion again. Those of the second pair move in a lower right direction. The legs of the first pair instead move in a upper right direction.

Driving the Piezo LEGS Motor

From the description of the drive leg, it can be seen that two phases are needed to achieve motion. The walking drive principle showed that two further drive phases are needed since two independent pairs of drive legs are used in the motor. For each drive leg, the applied signals are phase-shifted relative to each other to respective sides of the drive leg. The phase shift is normally set at 90°, and the phase shift between the two pairs of drive legs is normally 180°. Fig. 5 schematically illustrates the phase shift between drive voltages, in this case with sinusoidal voltages. The solid line corresponds to one pair of drive legs and the dashed line to the other.

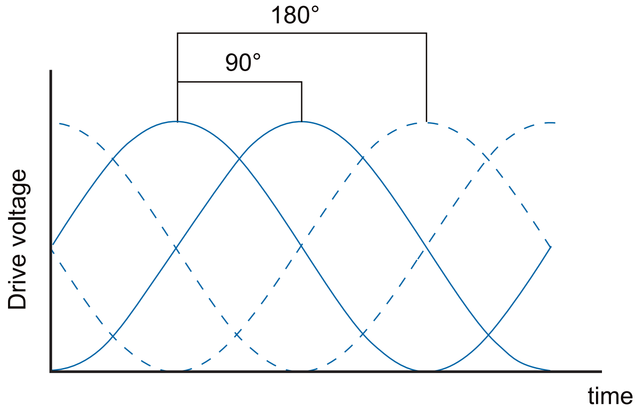


Fig. 5. Normal phase shifts between drive voltage signals.

PIEZO LEGS MOTOR CONSTRUCTION

Since the motor principle is based on friction forces between the drive rod and drive legs, a normal force is needed. There are a number of ways to create normal force, but using some type of spring is one of the simpler. The motor construction described below is for the demo-kit motor. This construction exemplifies the Piezo LEGS linear motor technology and can be altered and optimized for a given application.

In the Piezo LEGS linear motor, a minimum number of components are used, giving a simple and robust construction. The exploded view on the left of Fig. 6 shows the components of the motor. From the bottom to the top these are; the motor housing where the motor element and connector are mounted plus the drive pads (made of aluminum oxide) mounted on top of the drive legs, the drive rod, bearing holder, ball bearings and finally the springs. The drive rod is pressed against the drive pads via the ball bearings, which are preloaded with a certain force by the spring. The spring is mounted in the bearing holder, which in turn is screwed into the motor housing.

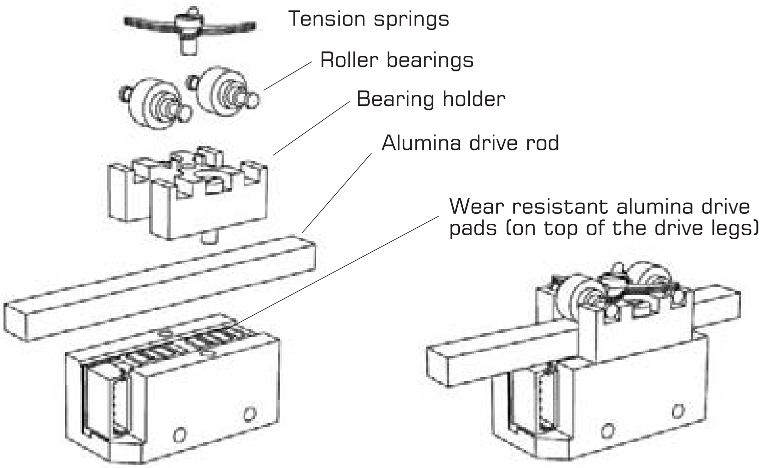


Fig. 6. The Piezo LEGS linear motor. The exploded view on the left shows the components for a complete motor. The assembled motor is shown on the right.

PIEZO LEGS MOTOR DRIVE DESIGNS

This section illustrates examples and discusses aspects of motor drive designs suitable for Piezo LEGS motors. In addition, one example of a simple positioning algorithm is given.

Waveforms and resolution

As mentioned above, the motor consists of two pairs of drive legs. Each pair is controlled by two analog signals normally having a voltage span of approximately 46 V. From an electrical point of view, the four motor phases may be considered as capacitors. Each phase of the Piezo LEGS demo motor has a capacitance in the order of 400 nF. The four capacitive motor phases are cycled up and down in voltage. Consider a waveform 1 (for motor phase 1). Waveform 2 should then be a mirror of waveform 1, whereas waveform 3 and 4 are identical to waveform 1 and 2, but phase-shifted half a cycle (180°). Fig. 7 shows one example. As Fig. 3 above has demonstrated, this waveform makes the drive legs move along the rhombic trajectory. Such a waveform is optimal for high speed, but the motion might be non-linear and a reversed direction of motion may occur during some parts of the drive cycle (gripping and releasing parts). Another waveform shown in Fig. 8 (only waveforms for one pair is shown) gives some 40% lower speed, but the motion is much more linear and even. Note that the step length and linearity depend on external forces. A strong external force opposing the motion can decrease the step length to almost zero, whereas the step length in the other direction is enhanced.

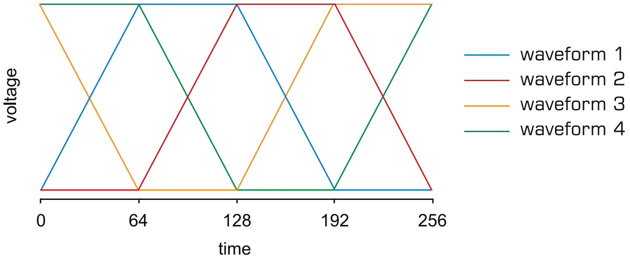
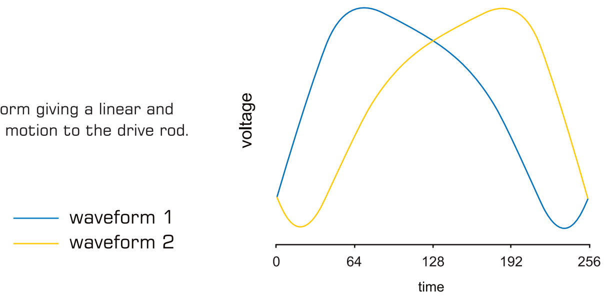


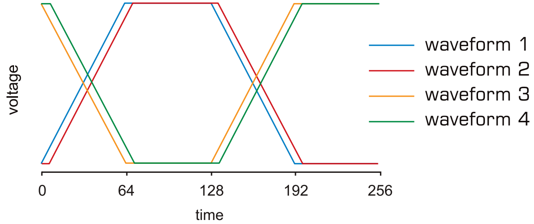
Fig. 7. Waveform to make the drive legs move along a rhombic trajectory.

Fig. 8. Waveform giving a linear and smooth, even motion to the drive rod.



Often, better resolution is preferable to maximum cycle step length. The step length can thus be made shorter by adjusting the phase shift between the waveforms. For example, the waveform in Fig. 9 gives around 10% of the step length of the waveform given in Fig. 7.

Fig. 9. Waveform giving a reduced step length.



However, fine-positioning at a level better than about 5% of maximum step length requires another solution, otherwise the "zigzagging" around the target position may be unacceptable. One solution is to divide the waveform into a number of points and step through the waveform point by point. This will be referred to as nano-stepping or the nano-step mode.

The maximum cycle step-length for the motors is normally in the range 4 to 8 μm. By using the phase-shift method, the resolution may at best be in the order of 200 nm. The nano-step mode can, however, increase resolution considerably. The achievable resolution will be a combination of the resolution of the D/A converter and the number of points in the waveform. Consider 256 points in a waveform, for example. This gives a resolution in the order of 20 nm (for a 4 μm cycle step-length). In this case, an eight-bit D/A converter gives high enough resolution.

Some waveforms, 256 points per cycle. Scale and add offset according to driver specification, e.g. u*44+3
u3/u4 is like u1/u2 but shifted half cycle

omega564 smoothwalking

n	u1	u2	
0	0.146447	0.146447	0.853553
1	0.159699	0.133673	0.857866
2	0.17341	0.121399	0.862127
3	0.187557	0.109642	0.866338
4	0.202119	0.09842	0.870502
5	0.217071	0.087749	0.874619
6	0.232389	0.077644	0.878691
7	0.248049	0.06812	0.882719
8	0.264024	0.059188	0.886705
9	0.280289	0.050859	0.890648
10	0.296818	0.043144	0.894551
11	0.313583	0.036051	0.898413
12	0.330558	0.029586	0.902234
13	0.347714	0.023755	0.906016
14	0.365025	0.018563	0.909758
15	0.382463	0.014011	0.913459
16	0.4	0.010102	0.917121
17	0.41761	0.006835	0.920741
18	0.435265	0.004208	0.92432
19	0.452939	0.00222	0.927855
20	0.470604	0.000865	0.931347
21	0.488235	0.000138	0.934794
22	0.505807	3.37E-05	0.938193
23	0.523294	0.000543	0.941544
24	0.540673	0.001657	0.944844
25	0.557919	0.003366	0.948091
26	0.57501	0.005658	0.951281
27	0.591923	0.008522	0.954413
28	0.608637	0.011945	0.957483
29	0.625133	0.015911	0.960488
30	0.64139	0.020408	0.963424
31	0.657391	0.025418	0.966288

sin1s64 standard sine

n	u1	u2
0	0.146447	0.146447
1	0.15523	0.137876
2	0.164221	0.129524
3	0.173414	0.121396
4	0.182803	0.113495
5	0.192384	0.105827
6	0.20215	0.098396
7	0.212096	0.091208
8	0.222215	0.084265
9	0.232501	0.077573
10	0.242949	0.071136
11	0.253551	0.064957
12	0.264302	0.059039
13	0.275194	0.053388
14	0.286222	0.048005
15	0.297379	0.042895
16	0.308658	0.03806
17	0.320052	0.033504
18	0.331555	0.029228
19	0.343159	0.025236
20	0.354858	0.02153
21	0.366644	0.018112
22	0.37851	0.014984
23	0.390449	0.012149
24	0.402455	0.009607
25	0.414519	0.007361
26	0.426635	0.005412
27	0.438795	0.00376
28	0.450991	0.002408
29	0.463218	0.001355
30	0.475466	0.000602
31	0.487729	0.000151

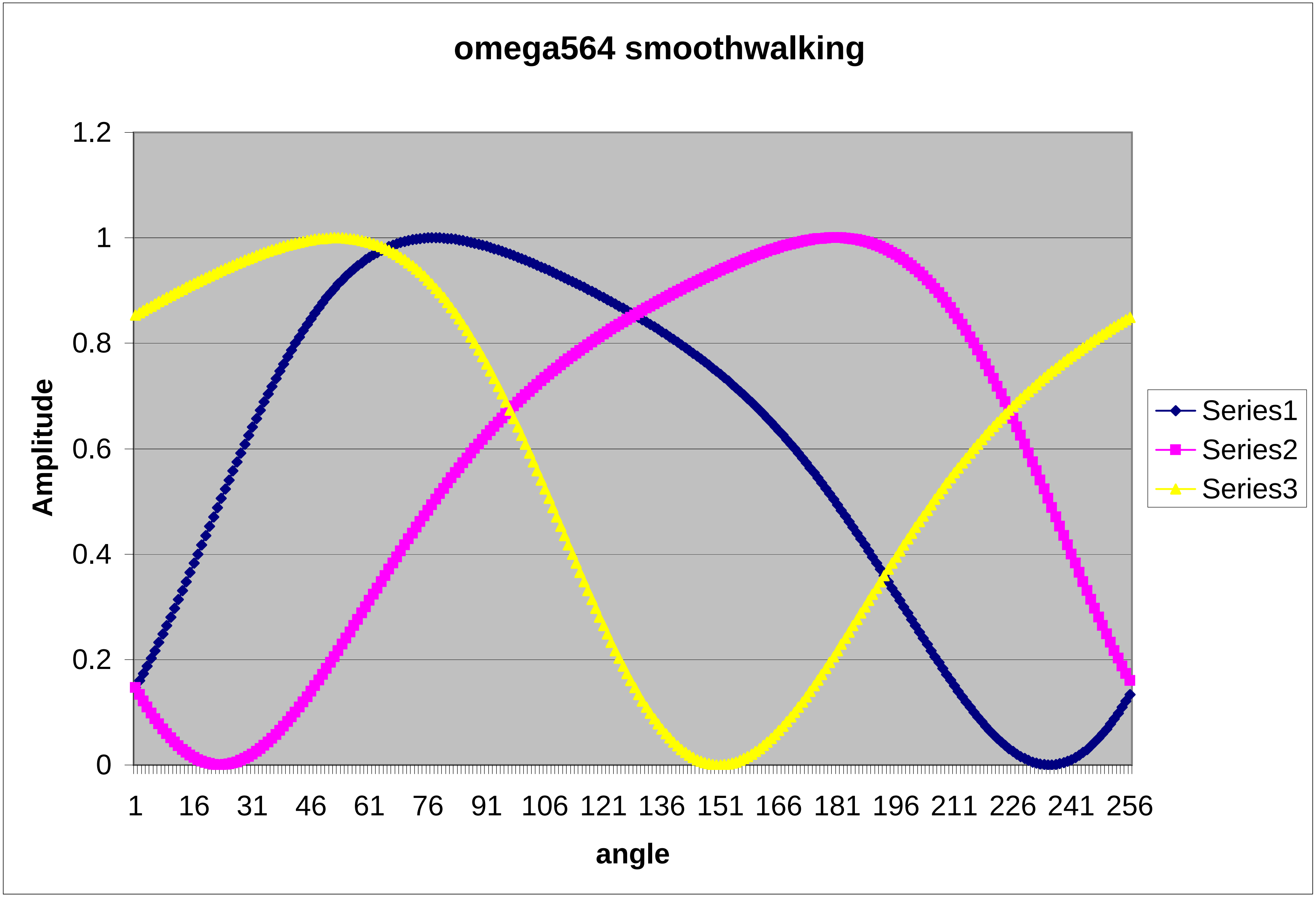
sin1s85 low sound

n	u1	u2
0	0.248231	0.248231
1	0.258908	0.237705
2	0.269731	0.227338
3	0.280692	0.217134
4	0.291785	0.207101
5	0.303004	0.197244
6	0.314341	0.18757
7	0.325791	0.178084
8	0.337345	0.168792
9	0.348997	0.1597
10	0.36074	0.150812
11	0.372567	0.142135
12	0.384471	0.133673
13	0.396444	0.125432
14	0.40848	0.117416
15	0.420571	0.109631
16	0.43271	0.102082
17	0.444889	0.094771
18	0.457101	0.087705
19	0.46934	0.080888
20	0.481596	0.074322
21	0.493864	0.068014
22	0.506136	0.061965
23	0.518404	0.05618
24	0.53066	0.050663
25	0.542899	0.045416
26	0.555111	0.040443
27	0.56729	0.035747
28	0.579429	0.03133
29	0.59152	0.027196
30	0.603556	0.023347
31	0.615529	0.019785

254	0.121399	0.17341	0.844767
255	0.133673	0.159699	0.849188

254	0.129524	0.164221
255	0.137876	0.15523

254	0.227338	0.269731
255	0.237705	0.258908


omega564 smoothwalking
Amplitude
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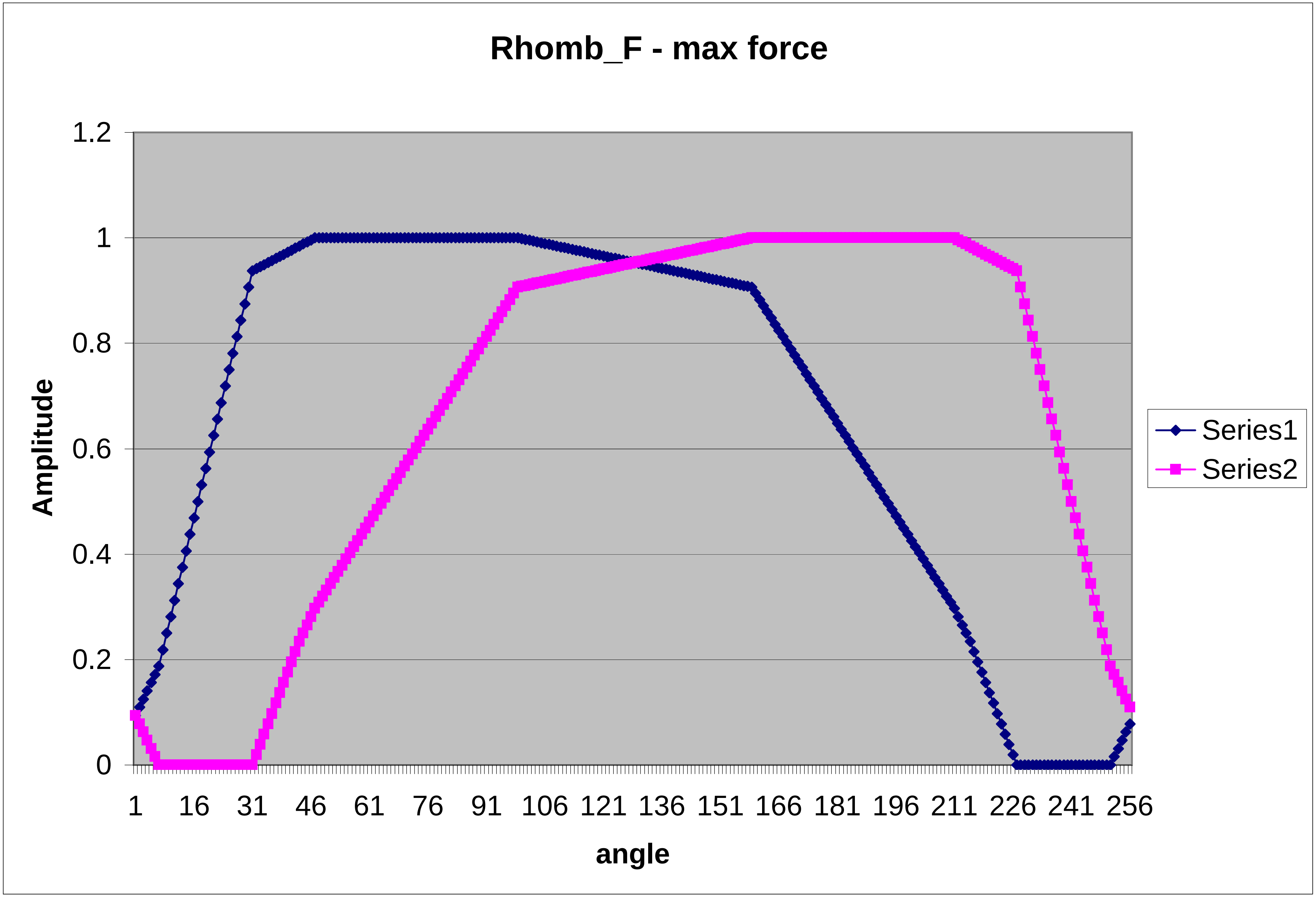
1
0.8
0.6
0.4
0.2
0
1
16
31
46
61
76
91
106
121
136
151
166
181
196
211
226
241
256
angle
Series1
Series2
Series3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0.6
0.4
0.2
0
1
16
31
46
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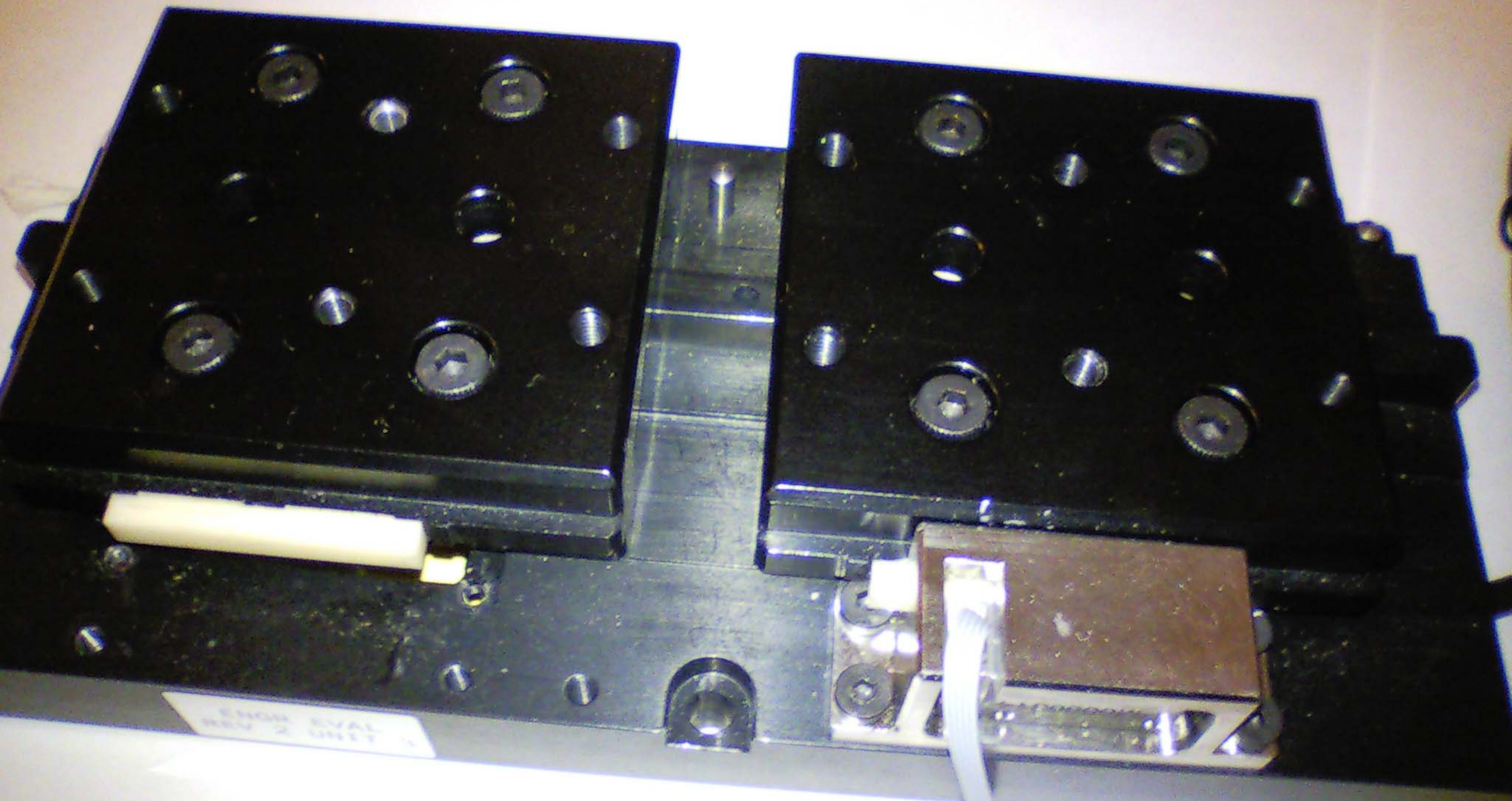
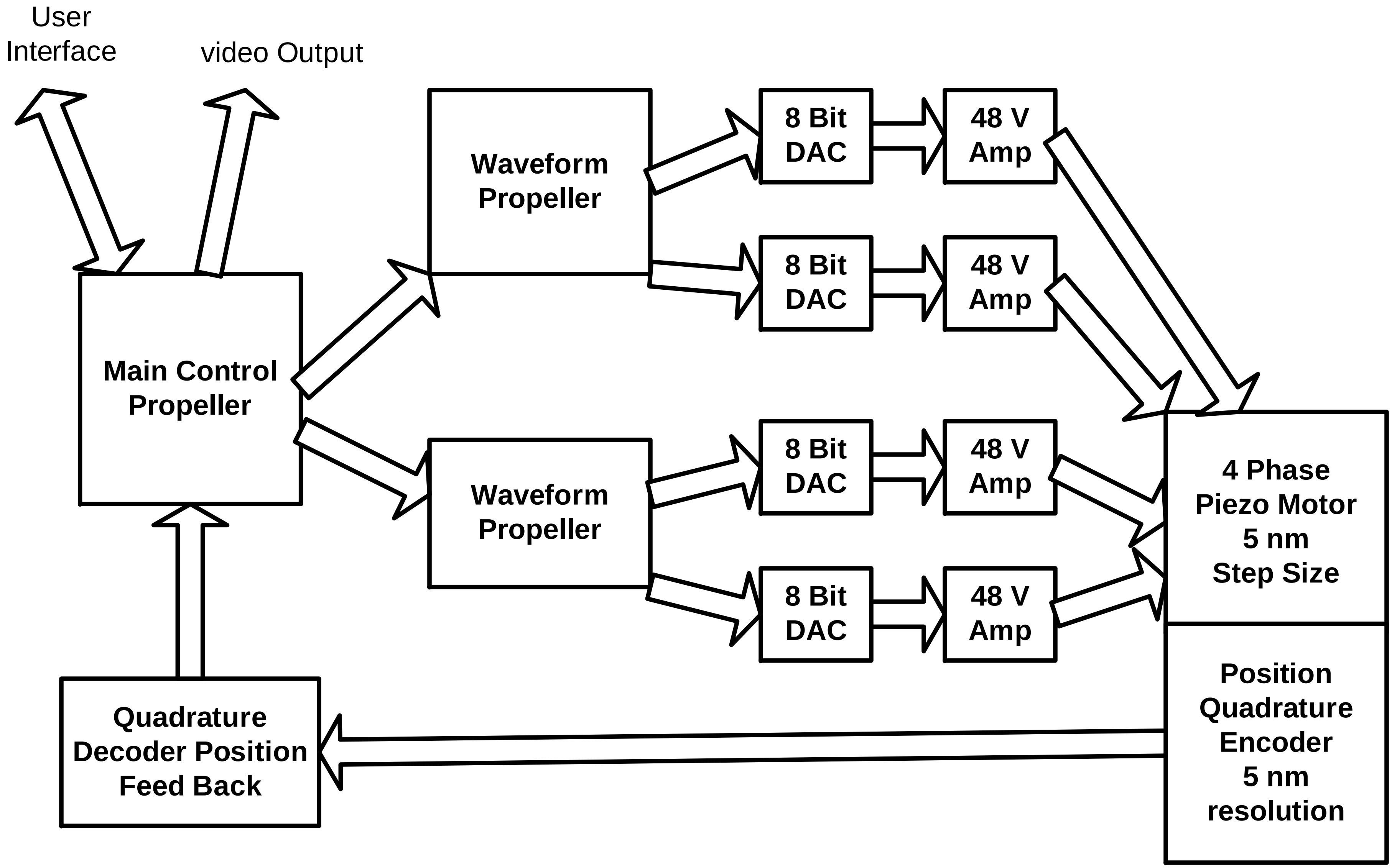
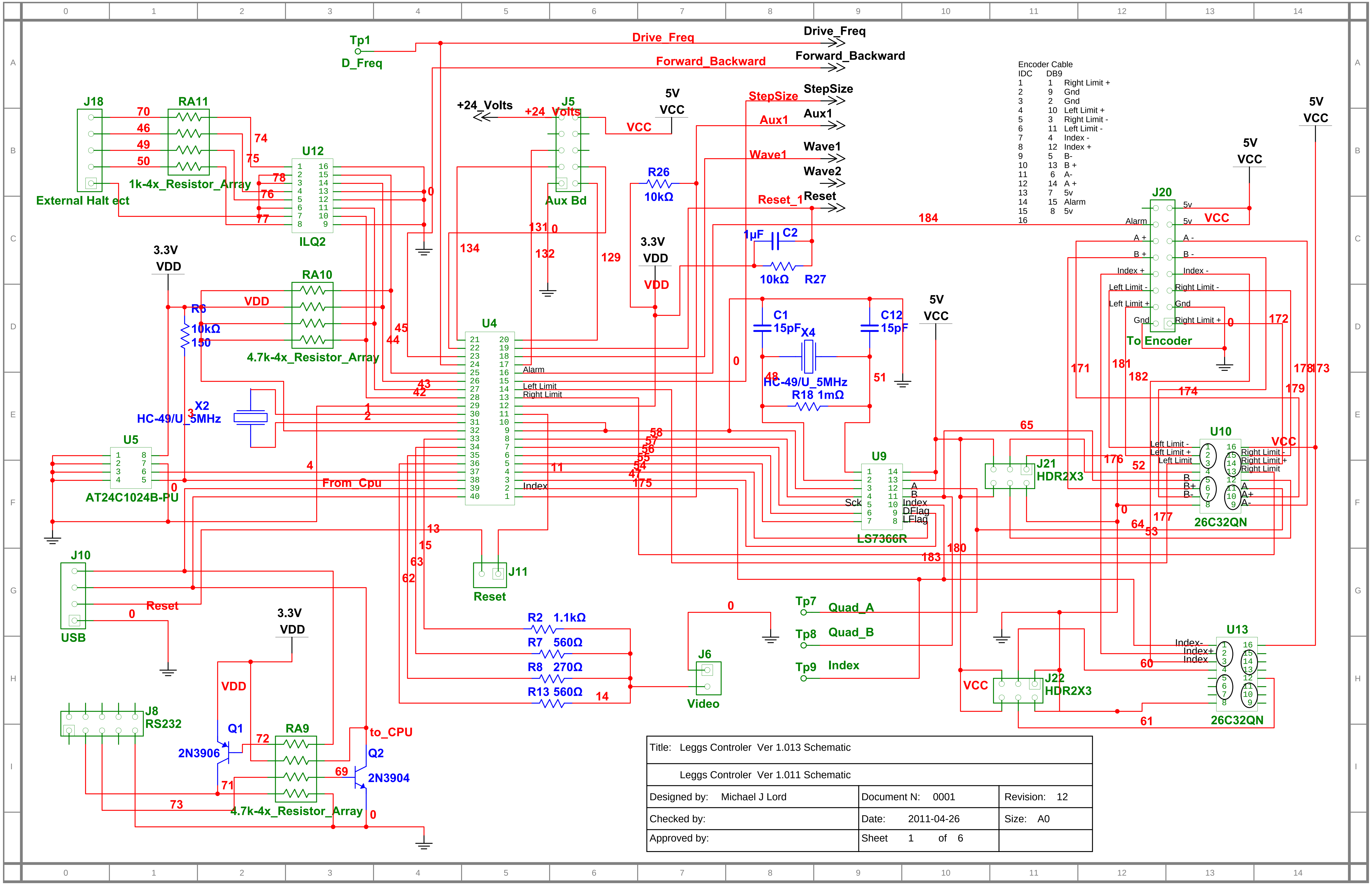
226
241
256
angle
Series1
Series2


ENGR EVAL
REV 2 UNIT 1

Closed Loop
MicroStep Piezo Motor Controller

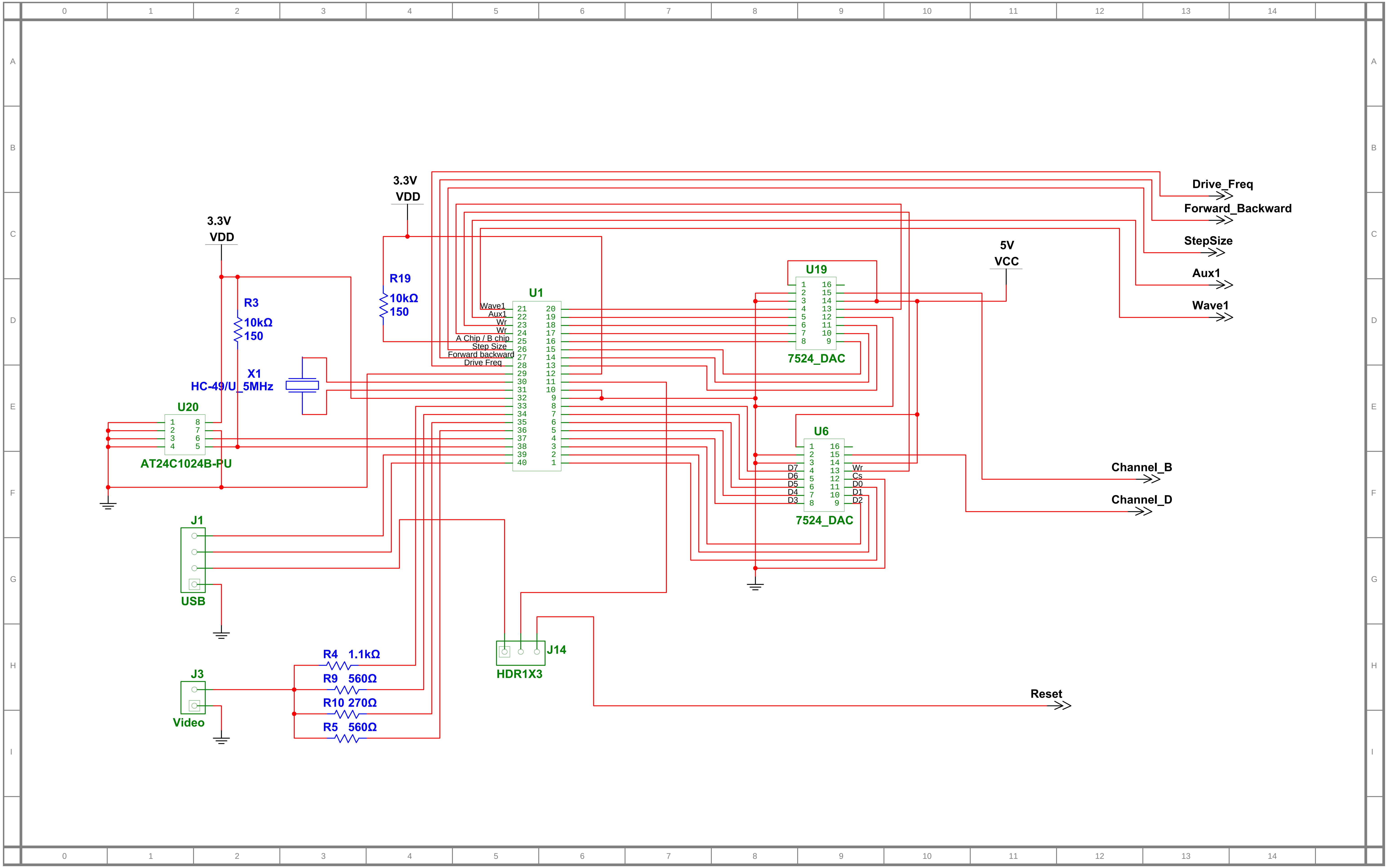




Encoder Cable

IDC	DB9	
1	1	Right Limit +
2	9	Gnd
3	2	Gnd
4	10	Left Limit +
5	3	Right Limit -
6	11	Left Limit -
7	4	Index -
8	12	Index +
9	5	B-
10	13	B +
11	6	A-
12	14	A +
13	7	5v
14	15	Alarm
15	8	5v
16		

Title: Leggs Controler Ver 1.013 Schematic		
Leggs Controler Ver 1.011 Schematic		
Designed by: Michael J Lord	Document N: 0001	Revision: 12
Checked by:	Date: 2011-04-26	Size: A0
Approved by:	Sheet 1 of 6	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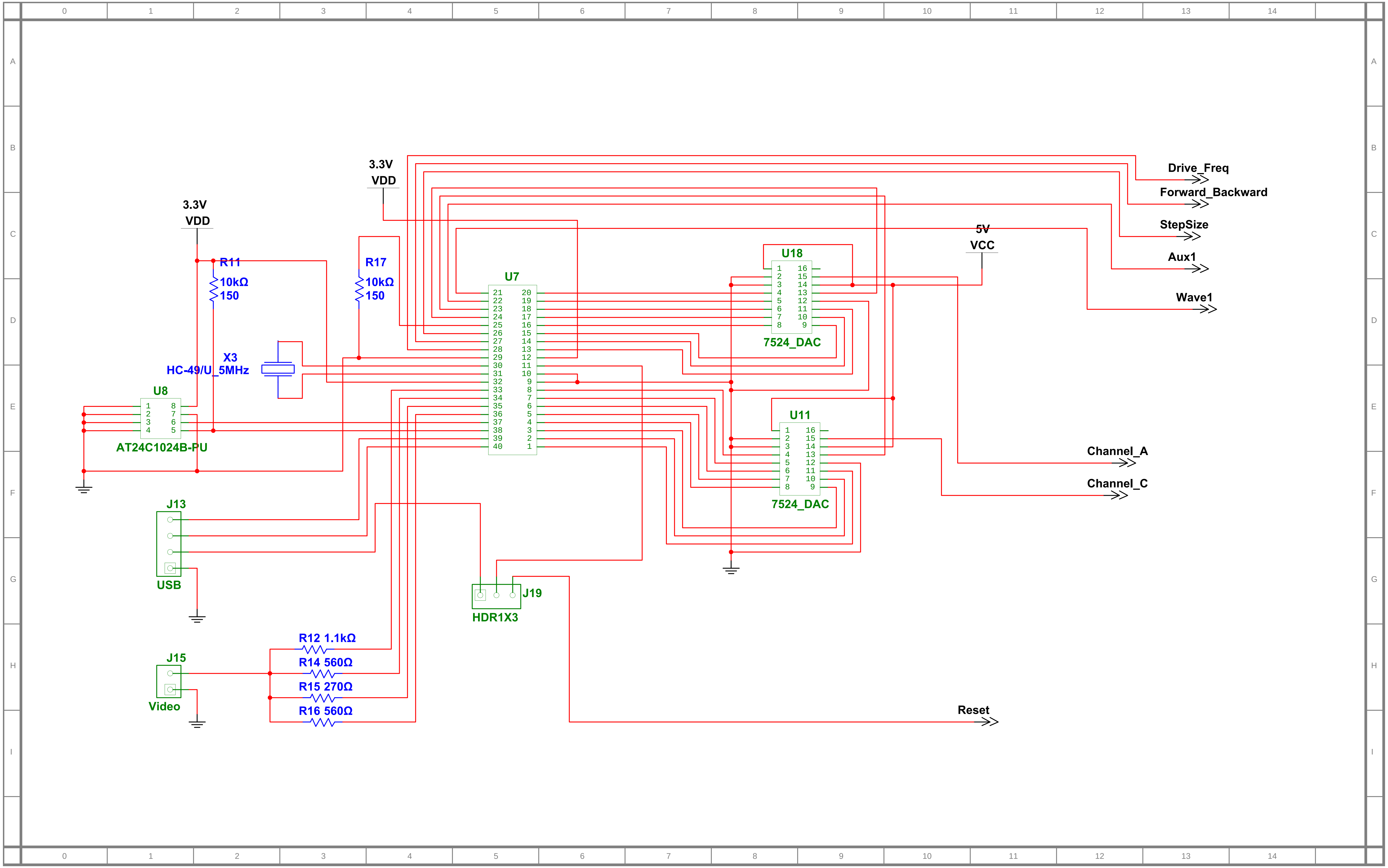
3.3V
VDD
R19
10kΩ
150
R3
10kΩ
150
X1
HC-49/U_5MHz
U20
1 8
2 7
3 6
4 5
AT24C1024B-PU
U1
Wave1
Aux1
Wr
Wr
A Chip / B chip
Step Size
Forward backward
Drive Freq
21 20
22 19
23 18
24 17
25 16
26 15
27 14
28 13
29 12
30 11
31 10
32 9
33 8
34 7
35 6
36 5
37 4
38 3
39 2
40 1
U19
1 16
2 15
3 14
4 13
5 12
6 11
7 10
8 9
7524_DAC
5V
VCC
Drive_Freq
Forward_Backward
StepSize
Aux1
Wave1
U6
1 16
2 15
3 14
D7 4 13 Wr
D6 5 12 Cs
D5 6 11 D0
D4 7 10 D1
D3 8 9 D2
7524_DAC
Channel_B
Channel_D
J1
USB
J14
HDR1X3
J3
Video
R4 1.1kΩ
R9 560Ω
R10 270Ω
R5 560Ω
Reset
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
A B C D E F G H I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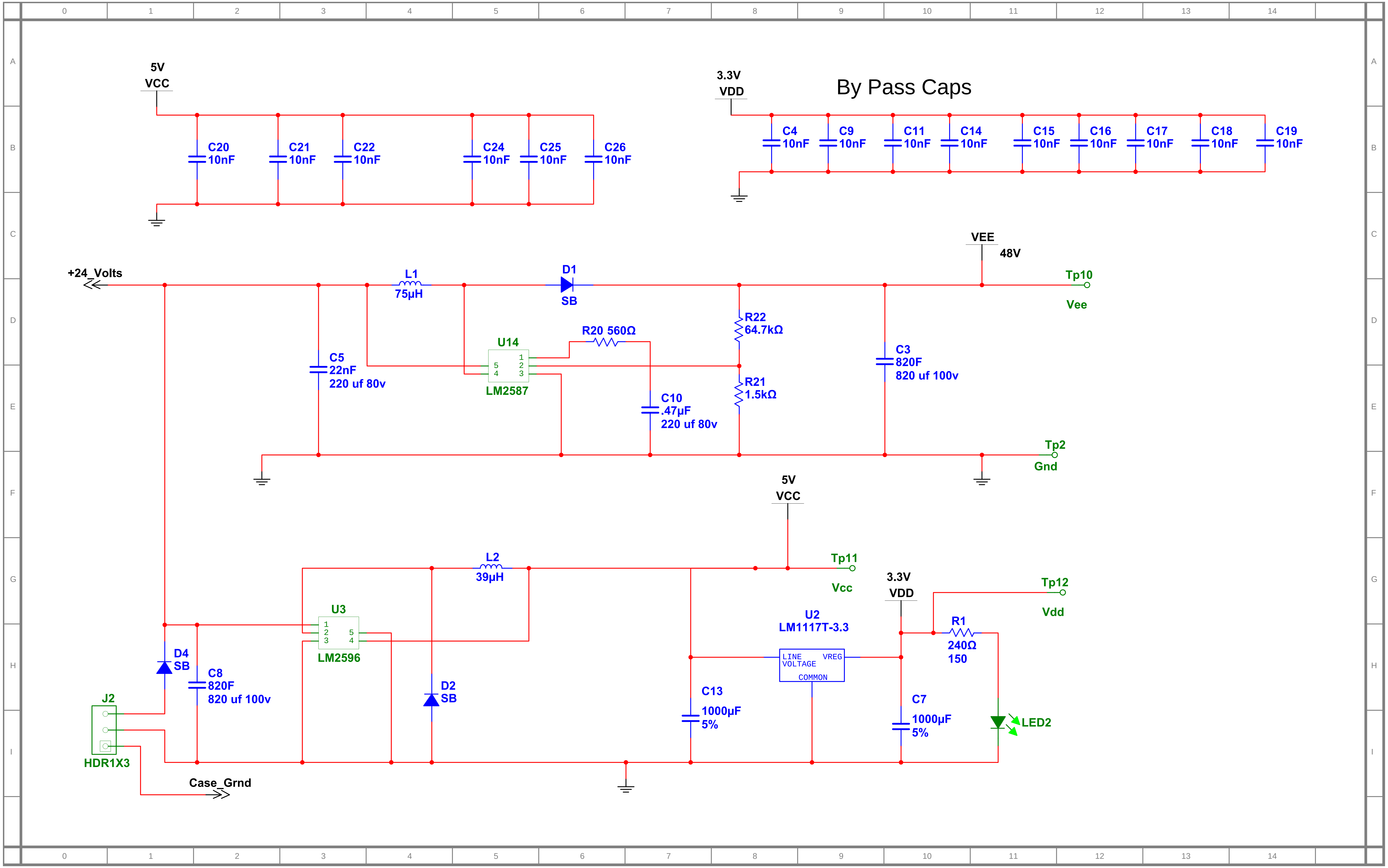
A B C D E F G H I
3.3V
VDD
R11
10kΩ
150
3.3V
VDD
R17
10kΩ
150
U7
X3
HC-49/U_5MHz
U8
AT24C1024B-PU
U18
7524_DAC
U11
7524_DAC
5V
VCC
Drive_Freq
Forward_Backward
StepSize
Aux1
Wave1
Channel_A
Channel_C
J13
USB
J19
HDR1X3
J15
Video
R12 1.1kΩ
R14 560Ω
R15 270Ω
R16 560Ω
Reset


By Pass Caps
5V
VCC
C20 10nF
C21 10nF
C22 10nF
C24 10nF
C25 10nF
C26 10nF
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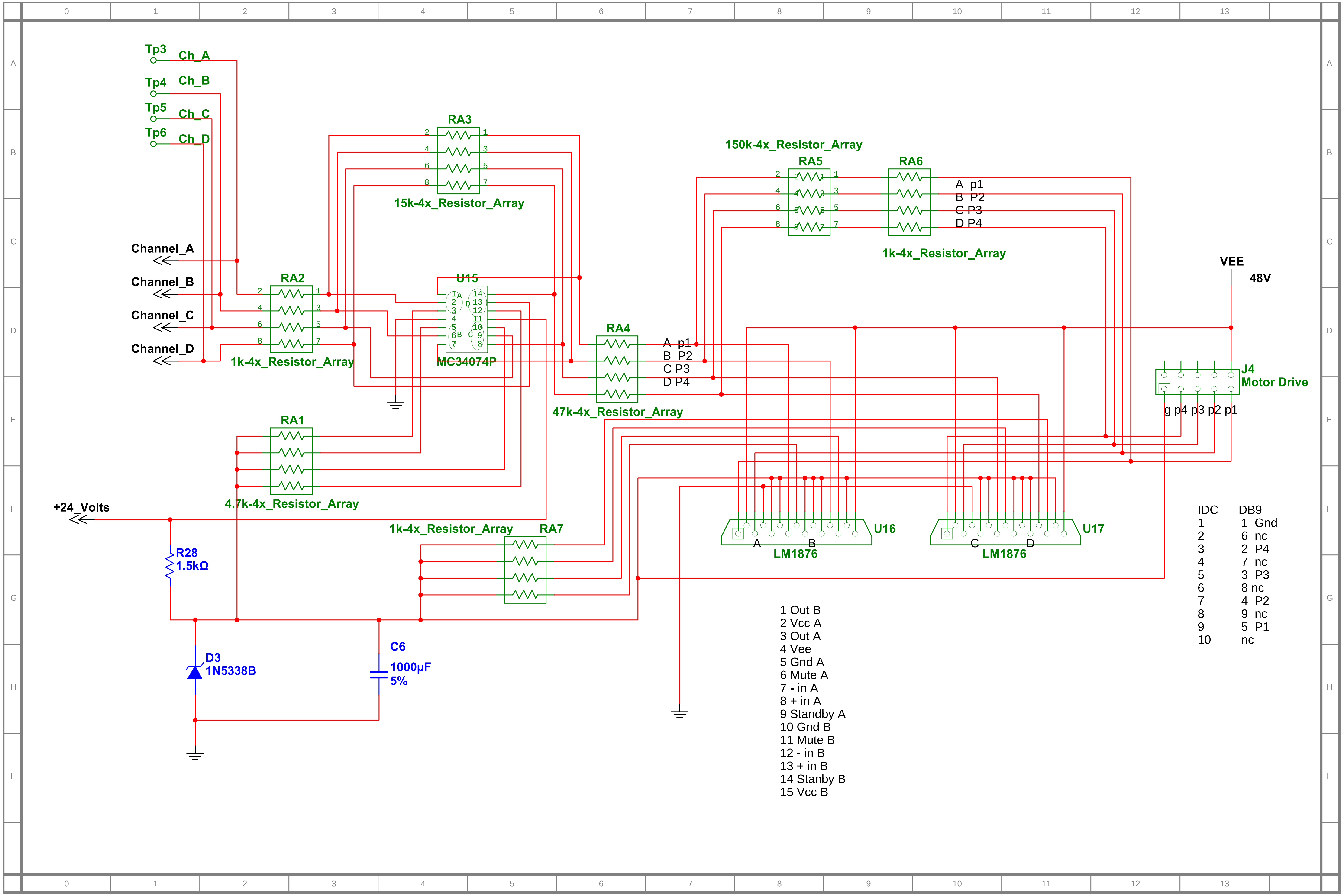
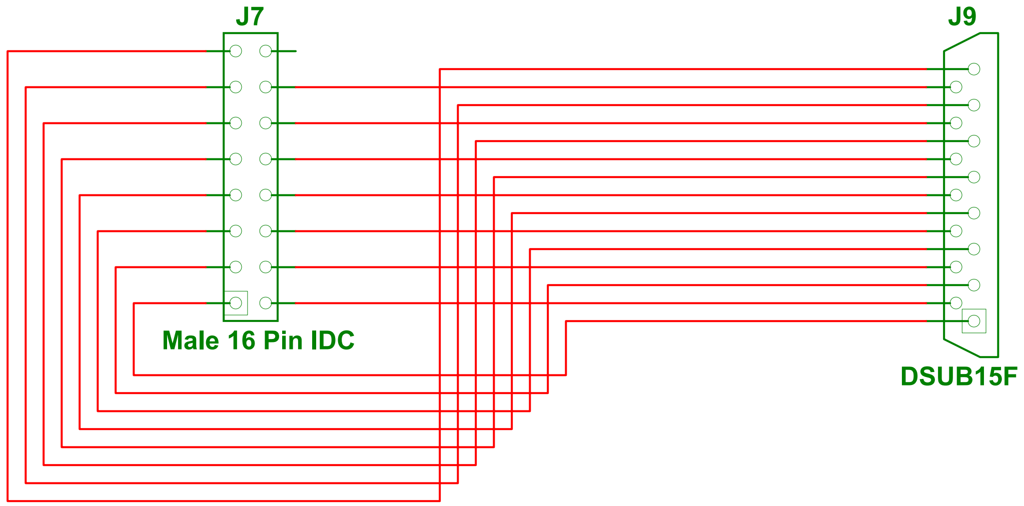
VDD
C4 10nF
C9 10nF
C11 10nF
C14 10nF
C15 10nF
C16 10nF
C17 10nF
C18 10nF
C19 10nF
VEE
48V
Tp10
Vee
+24_Volts
L1
75µH
D1
SB
R22
64.7kΩ
R20 560Ω
U14
LM2587
C5
22nF
220 uf 80v
C3
820F
820 uf 100v
R21
1.5kΩ
C10
.47µF
220 uf 80v
Tp2
Gnd
5V
VCC
L2
39µH
Tp11
Vcc
3.3V
VDD
Tp12
Vdd
U3
LM2596
U2
LM1117T-3.3
LINE VOLTAGE
VREG
COMMON
R1
240Ω
150
D4
SB
C8
820F
820 uf 100v
D2
SB
C13
1000µF
5%
C7
1000µF
5%
LED2
J2
HDR1X3
Case_Grnd
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
A B C D E F G H I



1 Out B
2 Vcc A
3 Out A
4 Vee
5 Gnd A
6 Mute A
7 - in A
8 + in A
9 Standby A
10 Gnd B
11 Mute B
12 - in B
13 + in B
14 Stanby B
15 Vcc B

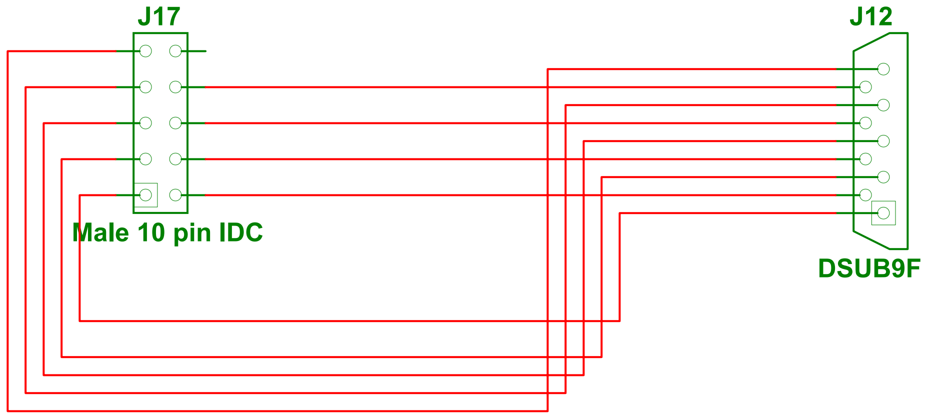
IDC	DB9
1	1 Gnd
2	6 nc
3	2 P4
4	7 nc
5	3 P3
6	8 nc
7	4 P2
8	9 nc
9	5 P1
10	nc

Encoder Cable



Encoder Cable

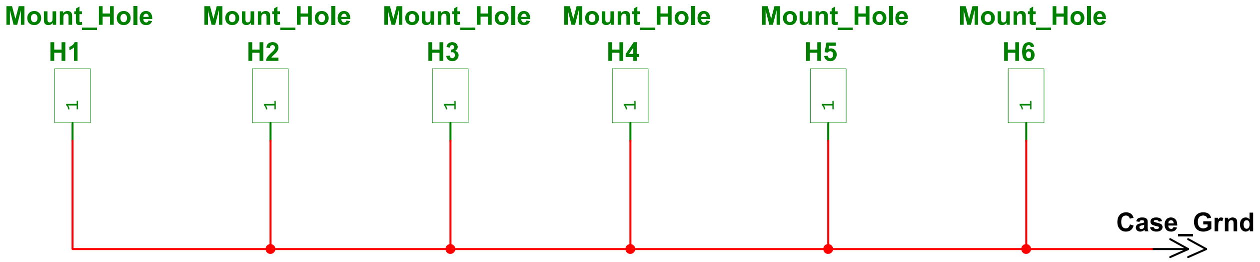
IDC	DB9	
1	1	Right Limit +
2	9	Gnd
3	2	Gnd
4	10	Left Limit +
5	3	Right Limit -
6	11	Left Limit -
7	4	Index -
8	12	Index +
9	5	B-
10	13	B +
11	6	A-
12	14	A +
13	7	5v
14	15	Alarm
15	8	5v
16		



Motor Cable

IDC	DB9	
1	1	Gnd
2	6	nc
3	2	P4
4	7	nc
5	3	P3
6	8	nc
7	4	P2
8	9	nc
9	5	P1
10	nc	

Motor Cable



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