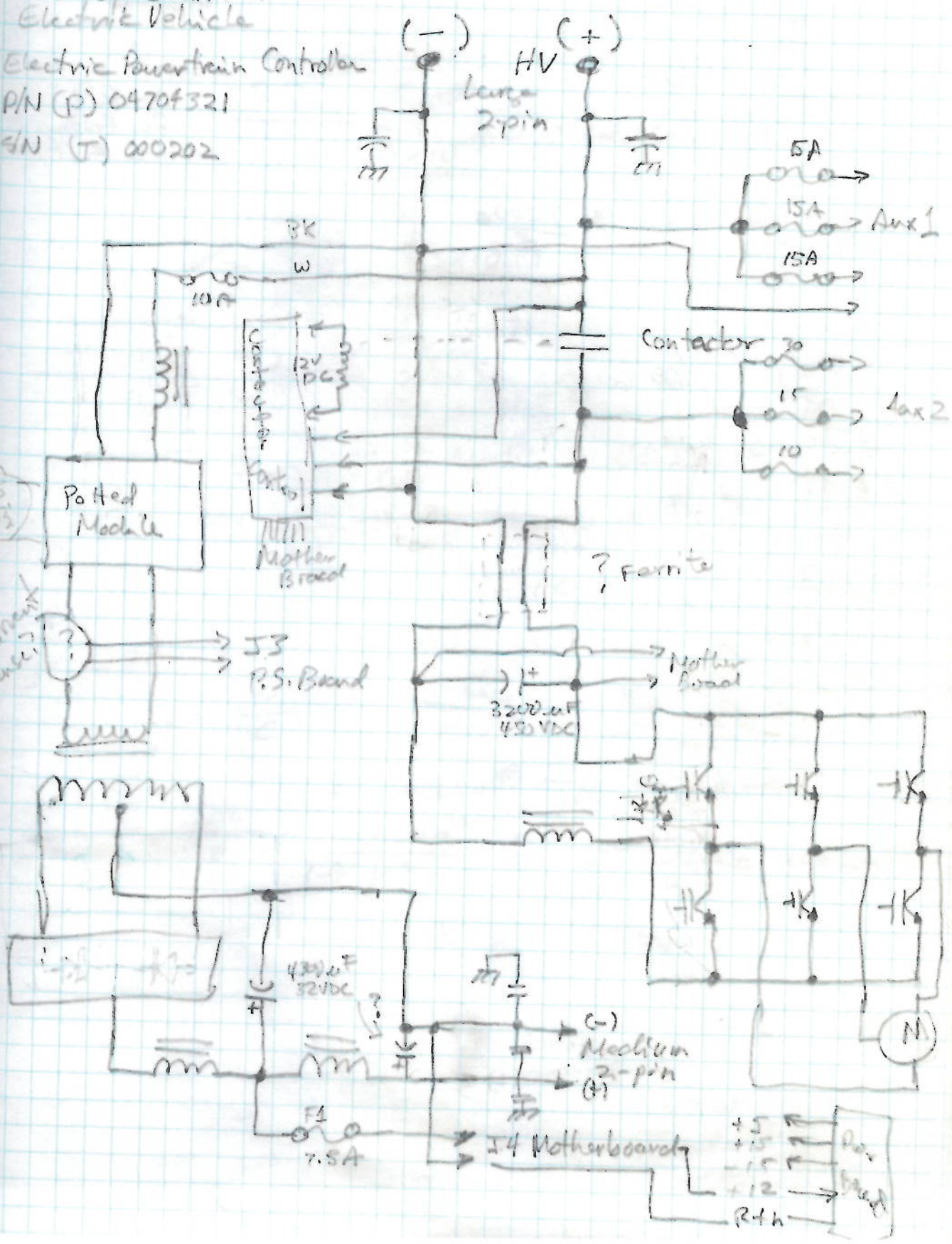
Northrop Grumman
Electric Vehicle

Electric Powertrain Controller
P/N (P) 04704321
S/N (T) 000202



9 msec

AC Motor

synchronous speed $n = \frac{120 \times f}{p}$

n = RPM
f = freq, Hz
p = # of poles

$120 \times 60 = \frac{7200}{p}$

p	n
2	3600
4	1800
6	1200
8	900

60 Hz = 17 msec period

$np = 120 \times f$

$f = \frac{np}{120}$

$$V_{ripple} = \frac{I \cdot 8.3\,ms}{C}$$

$$C = \frac{I \cdot 8.3 \times 10^{-3}}{V_r}$$

$$= \frac{15 \cdot 8.3 \times 10^{-3}}{10}$$

$$= 12.5 \times 10^{-3}$$

$$= .0125\,F$$

$$= 12500\,\mu F$$

for $V_R = 1\,V = 125{,}000\,\mu F$

$$\Delta V = \frac{I}{2fC}$$

$$\Delta V = \frac{I \cdot 8.3}{C}$$

$I = mA$

$C = \mu F$

$$\frac{15 \cdot 8.3}{10}$$

$$C = \frac{I \cdot 8.3}{\Delta V}$$

$$\frac{15 \times 10^{-3} \cdot 8.3}{10}$$

$$\frac{15 \times 10^{-3} \times 8.3}{10}$$

$$125 \times 10^{-2}$$

$$125.00$$

$\tau = RC$

$$R = \frac{\tau}{C} = \frac{10\,sec}{10{,}000\,\mu F} = \frac{10}{10^{-2}}$$

$$= \frac{1}{10^{-3}} = 1\,k\Omega$$

$$P = \frac{E^2}{R} = \frac{(1.4 \cdot 220)^2}{10^3} \approx \frac{100 \times 10^3}{10^3} = 100\text{ watts}$$

$100\,sec = 10K = 10$ watts

$10{,}000\,\mu F$

$10 \times 10^3 \times 10^{-6}$

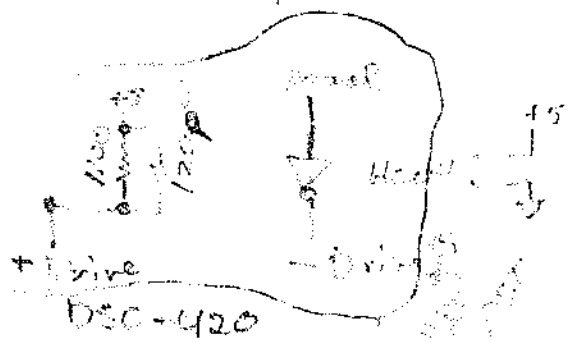
10×10^{-3}

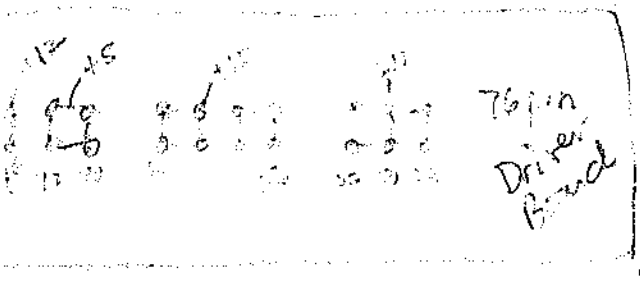
[illegible] Board [illegible]

+ Drive 36 - 38 [illegible] from [illegible] chip

[illegible] 35 37 39 41 43 45 from [illegible] inverter ?

[illegible] 45





Blue 1 — 2 — 35 — 30 → J1H

Green 5 — 6 — 37 — 32 → J1L

[illegible] 6 — 39 — 34 → J2H

[illegible] 13 — 12 — 41 — 36 → J2L

Green 3 — 4 — 43 — 38 → J3H

[illegible] 11 — 10 — 45 — 40 → J3L

H = 6,7
L = 3,4

LM317T [illegible]

$V_o = 1.25(1 + R_2/R_1)$

$V_o = 1.25 + \frac{1.25 R_2}{R_1}$

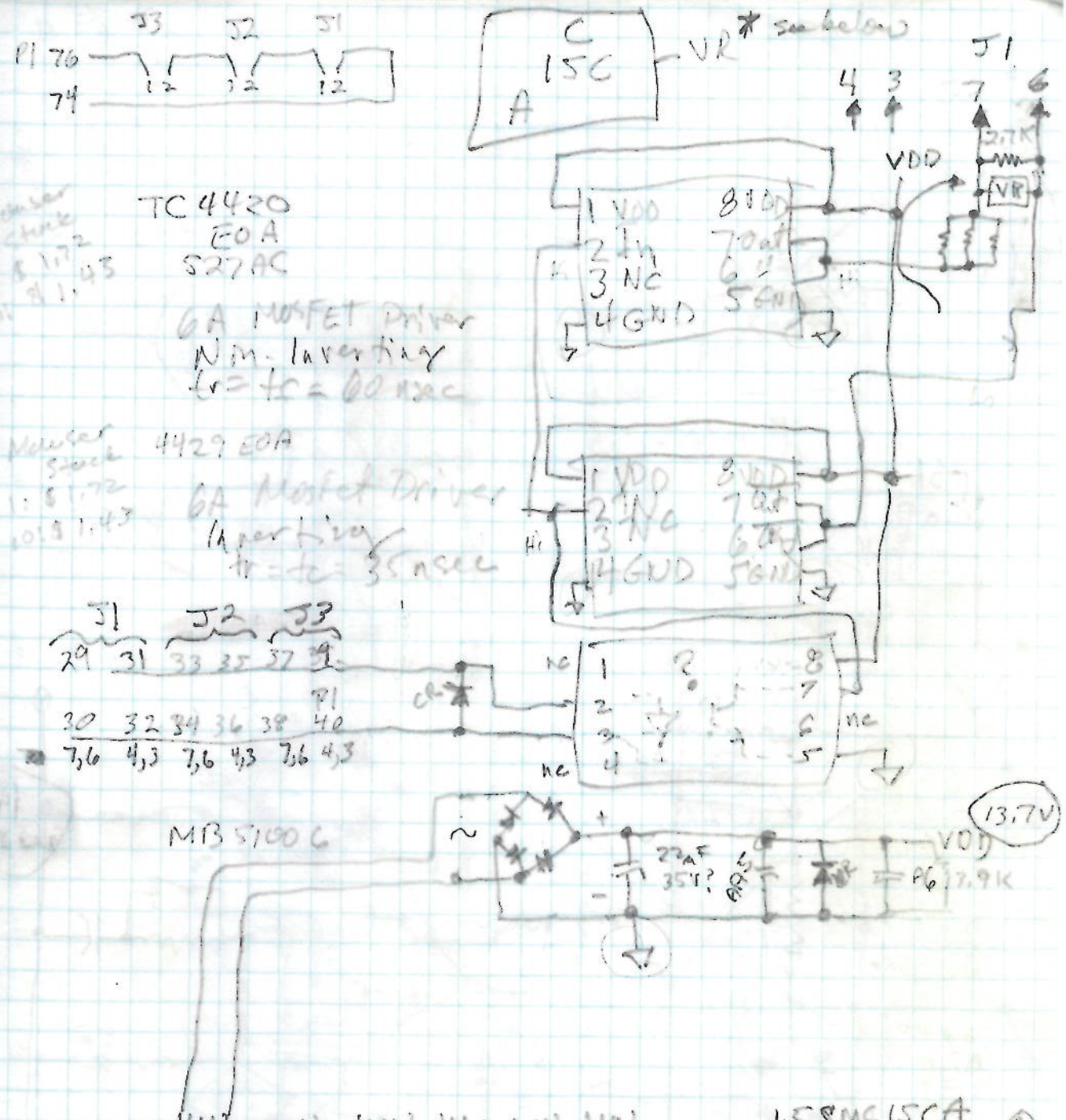
$15 = 1.25 + 1.25 R_2/R_1$

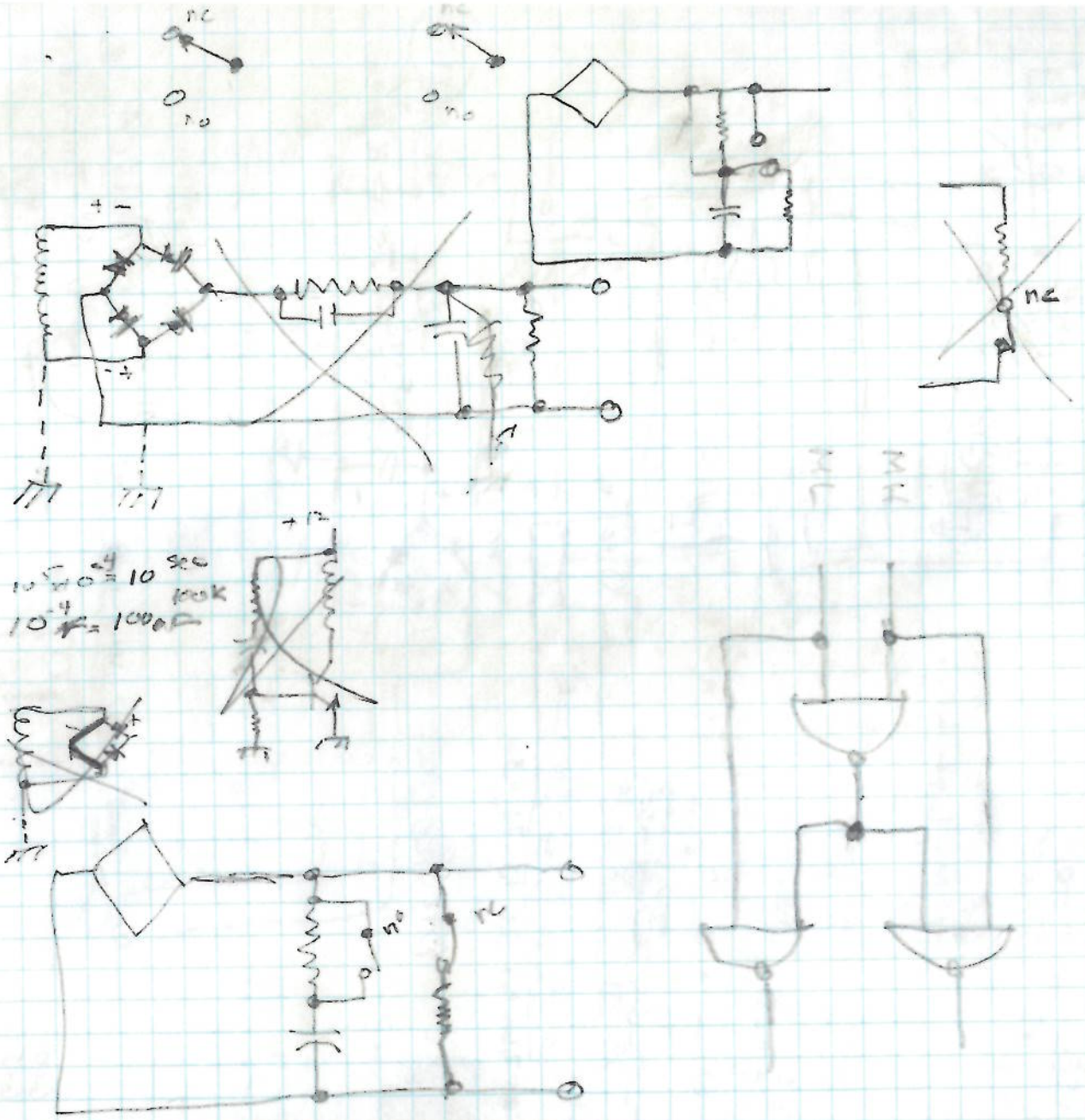
$13.75 R_2/R_1 = 13.75$

$R_2/R_1 = \frac{13.75}{1.25} = 11$

$\Rightarrow R_1 = 100$ 750 [illegible]

$R_2 = 1.1k$ [illegible] 3K


J3 J2 J1
P1 76 74
12 12 12
C 15C A
VR * see below
J1
4 3 7 6
2.7K
VDD
VR
TC4420
EOA
527AC
6A MOSFET Driver
Non Inverting
tr = tf = 60 nsec
4429 EOA
6A Mosfet Driver
Inverting
tr = tf = 35 nsec
1 VDD
2 IN
3 NC
4 GND
8 VDD
7 OUT
6 "
5 GND
J1 J2 J3
29 31 33 35 37 39
30 32 34 36 38 40
P1
7,6 4,3 7,6 4,3 7,6 4,3
nc
MB5100G
22uF
35V?
13.7V
VDD
7.9K
1.5SMC15CA
* VR = Transzorb
Vishay TVS Diode
Bi directional
1500 W
VBR
min max
14.3 15.8
Standoff
12.8V
Max Clamp 21.2V
Max Peak Pulse 70.8A
+15
100
100
UC3112 40W
600
605
14.9
14.5

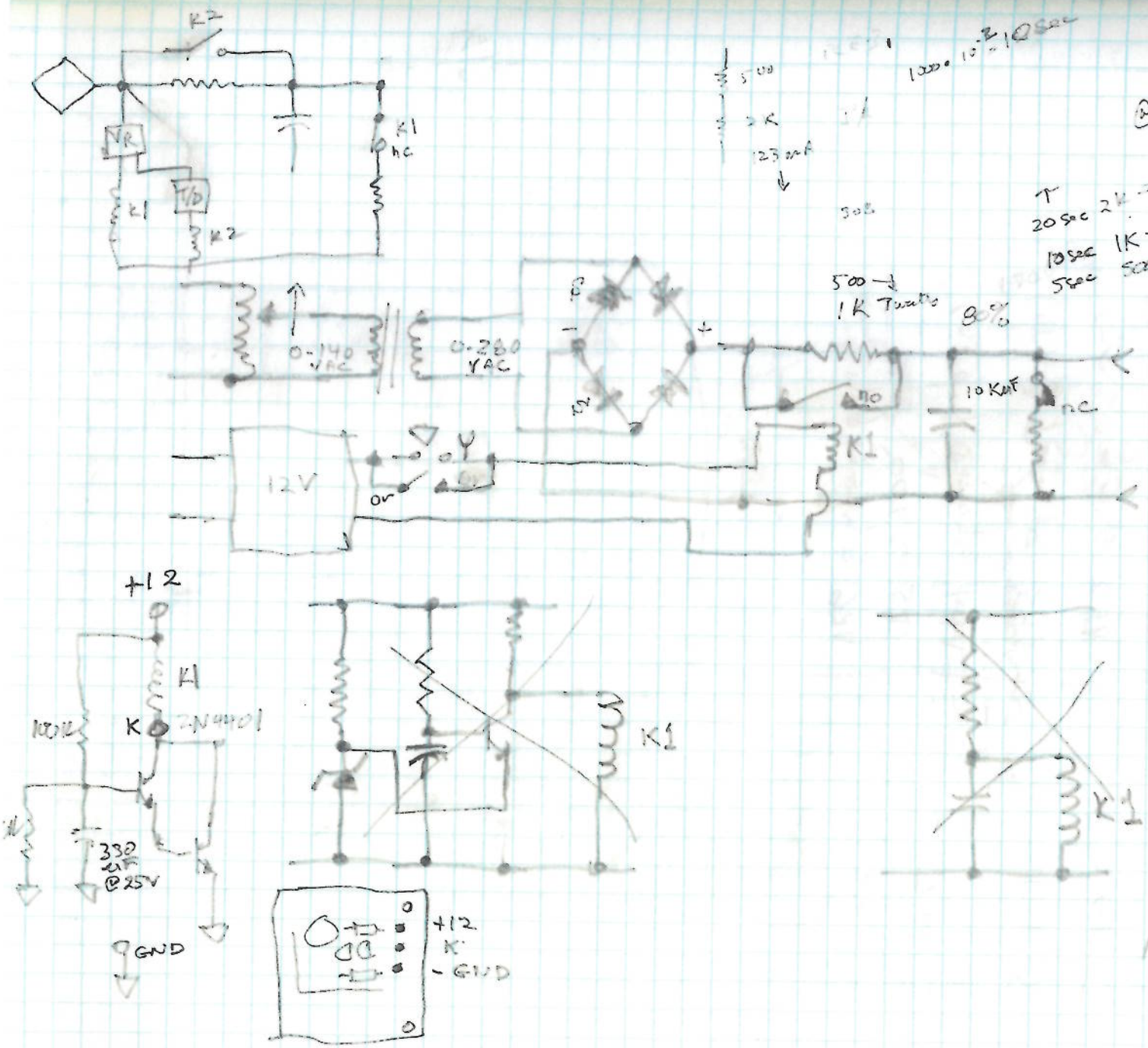


$10^{-4}\Omega = 10$ sec

$10^{-4}F = 100\mu F$

K2

10^{-2} 10 sec


K2
K1
nc
K1
K2
0-140 VAC
0-280 VAC
500
2K
123 mA
1000 10 = 10 sec
@170 vdc
20 sec 2K → 34 mA → 15 watt
10 sec 1K → 170 mA - 30 watt
5 sec 500 → 340 mA - 60 watt
500 → 1K Watts
80%
10 Kuf
nc
no
K1
12V
or
+12
K1
K
2N4401
100K
330 uF @25V
GND
K1
+12
K
- GND
K1
nom. 12VDC
Operate 9V
86 Ω
140mA @ 12

Briver Board Bridge Voltage

PS 14.3

From left

1	10.4	
2	10.2	
3	11.1	
4		11.5
5	12.6	
6	10.2	

VR1 2700 Ω

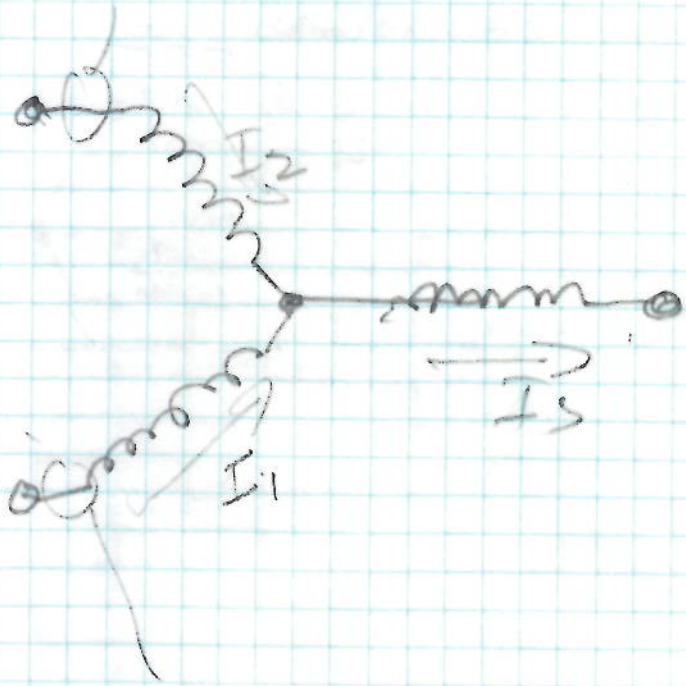
VR2 shorted (.2Ω)

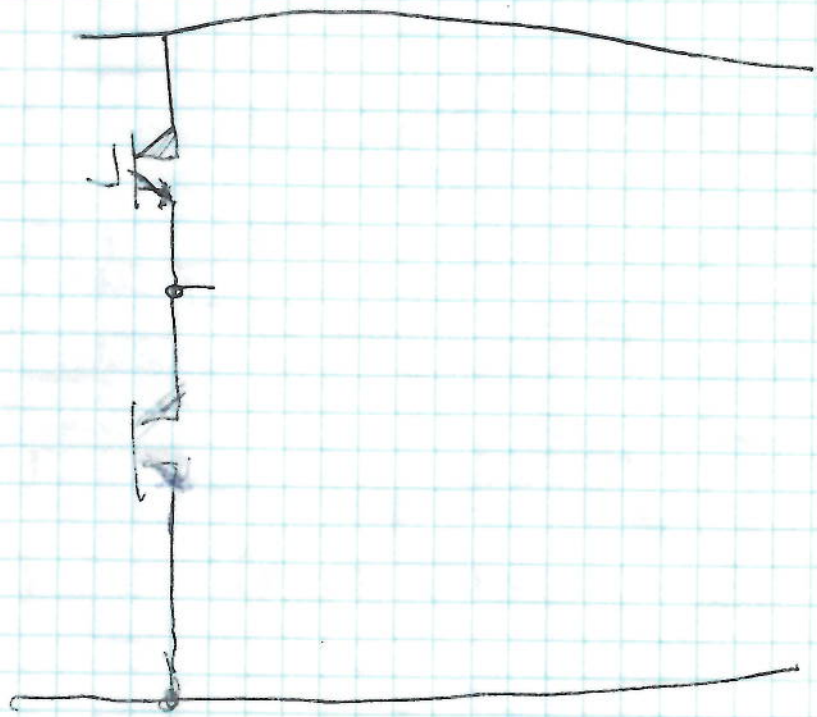
VR3 shorted (.4Ω)

VR4 shorted (.6Ω)

VR5 2700 Ω

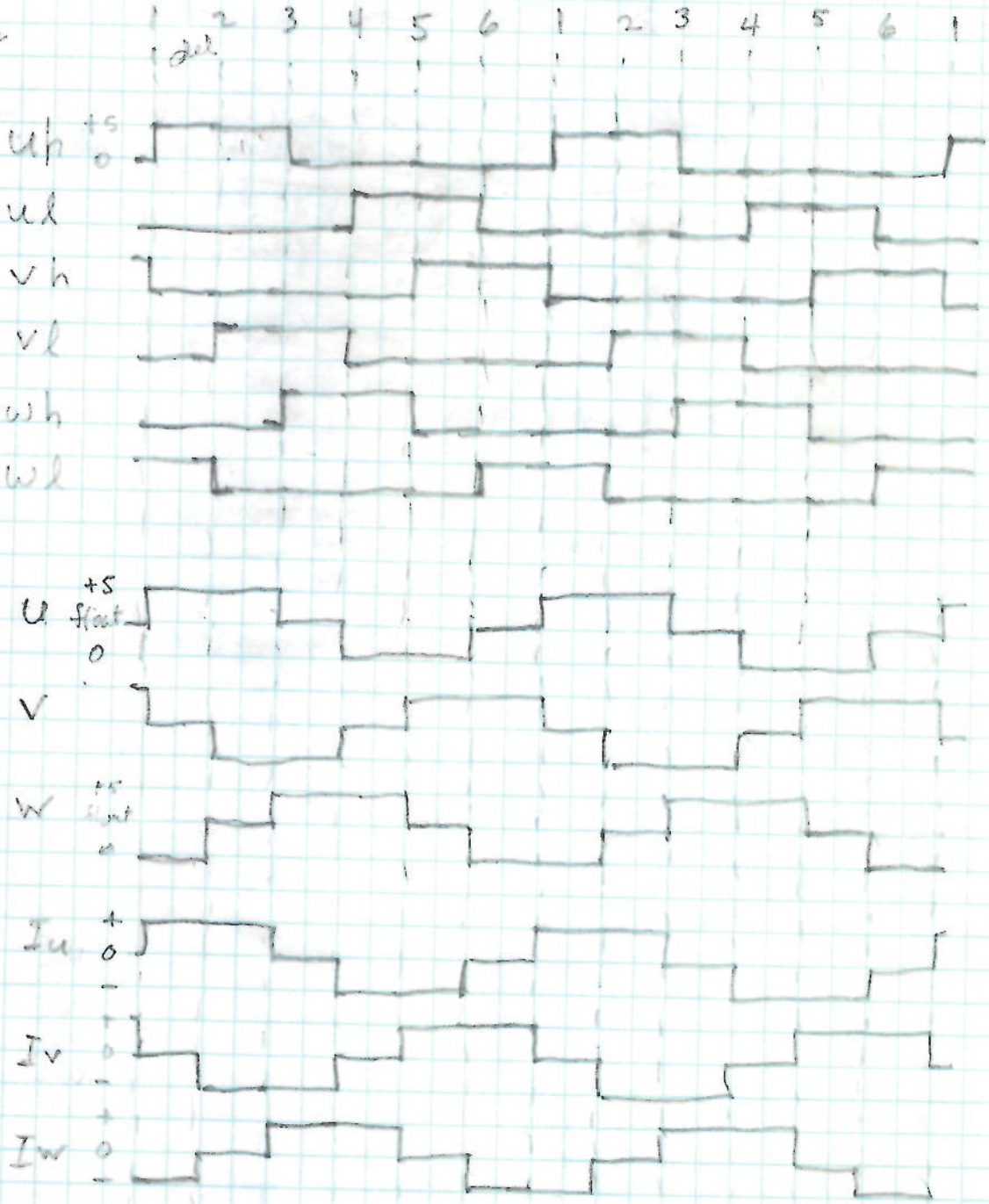
VR6 shorted 1.2


I_2
I_3
I_1



sixStepSketch.C © 2009 Will Brunner

code.google.com/p/threephase

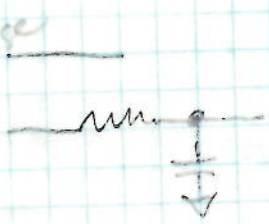


Audi TT ECU Replacement

		Price	Ship	Warranty/ Return
✓	innovative-autosports 99.6% Renton WA 14 day money back or refund buyer's choice	$239.95	0	Lifetime / 14 days
Zarcial	gotfreak187 100% "fully tested" in Ohio	$295.00	0	/ 14
X	mini-genie 99.5% 25% restock + ship cost ← say 18ITP (AWP)	$144.99	0	120 / 30
	greenlightusedautoparts money back or replacement sellers opt. of vehicle in CA	$200	0	30 / 30
X	209mohamedali 97.4% "tested"	$105	0	no returns

CD 4013 Dual "D" F/F
CD4016 Quad Bilateral Switch
CD 4049 Hex Inv. Buffer
CD40106 BE Hex Schmidt Trigger, Inv
CD4081BE Quad 2 in AND
CD4093 BE Quad 2 in NAND Schmitt Trigger

My Three Phase



Max Freq @ 48 steps/period/step

Minimum Pulse Width

@ 31.25 KHz, 32 usec period, 8 bit, $\frac{1}{255} \cdot 32$ usec = 125 nsec

@ 3.906 KHz, 256 usec period, 8 bit, $\frac{1}{255} \cdot 256$ = 1 usec

Freq	steps 48	24	12	
31.25	651	325	162	Hz
3.906	81	40	20	Hz

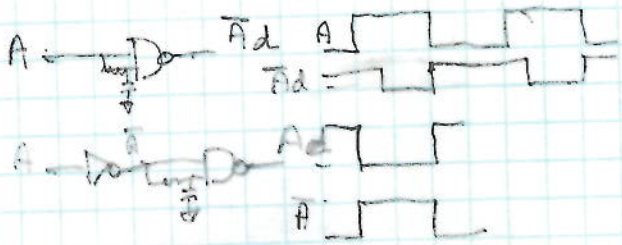
w/ motorDelay = 1 and using millis and potState divisor = 100
48 steps get max sine freq = 20.4 Hz
Flat out = 130 Hz

24 steps = 41 Hz

12 steps 83 Hz

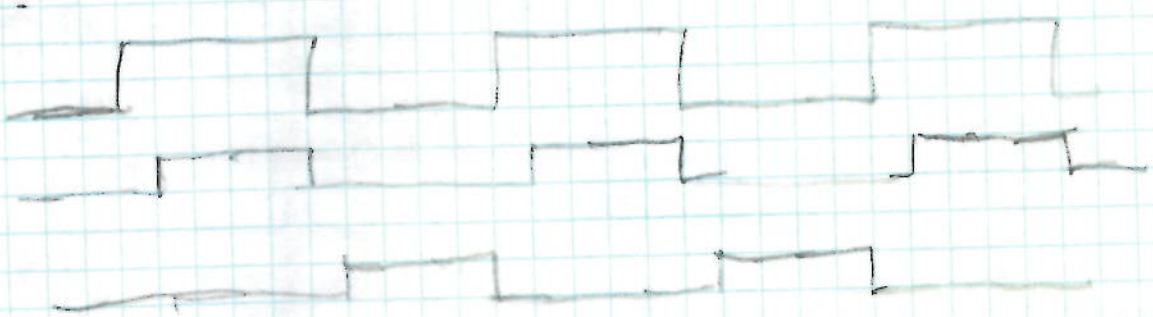
— o — Revised program to simply delay in main loop using delayMicroseconds + mapping pot to range of:

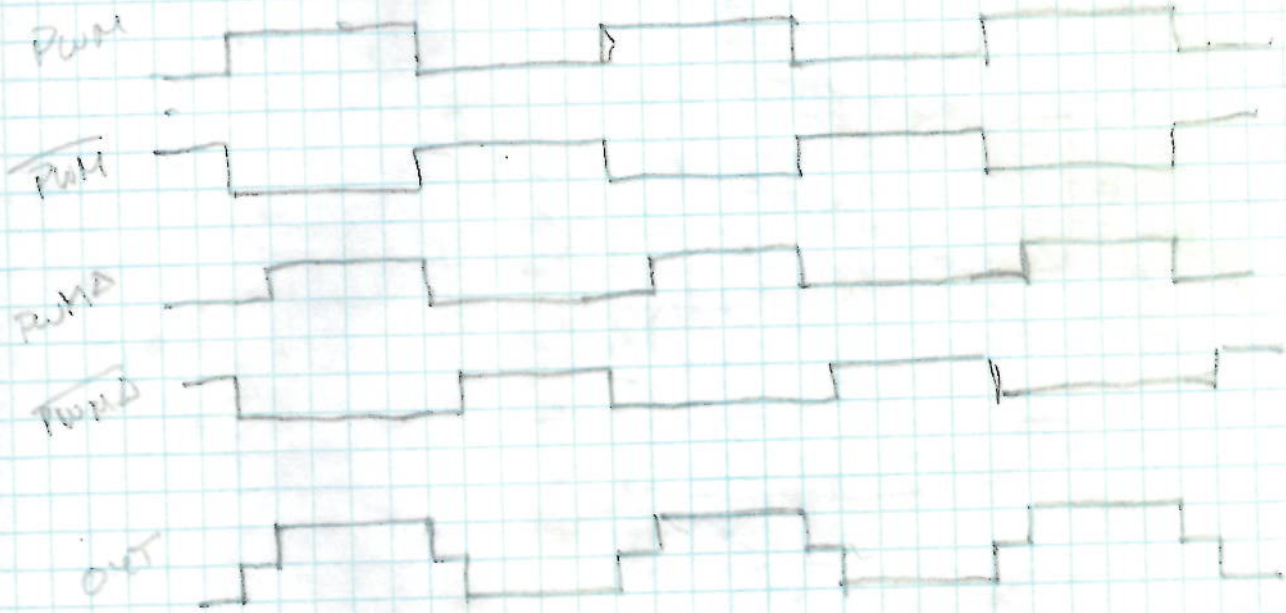
8 bit, 31.7 KHz
100, 1000 → 57 usec - 14.2 msec
17.5 Hz → 70.4 Hz
100, 2000 → 106 msec - 14.2 msec
9.4 Hz → 70.4 Hz ✓

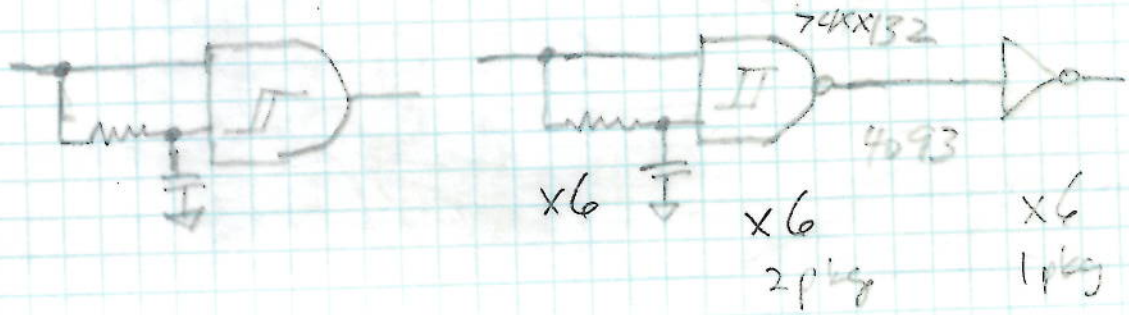


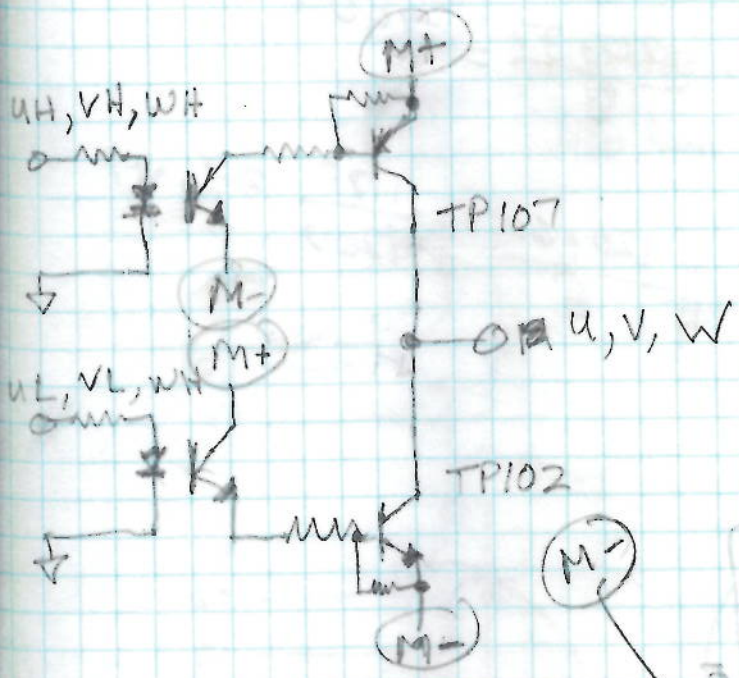
My_three_phase

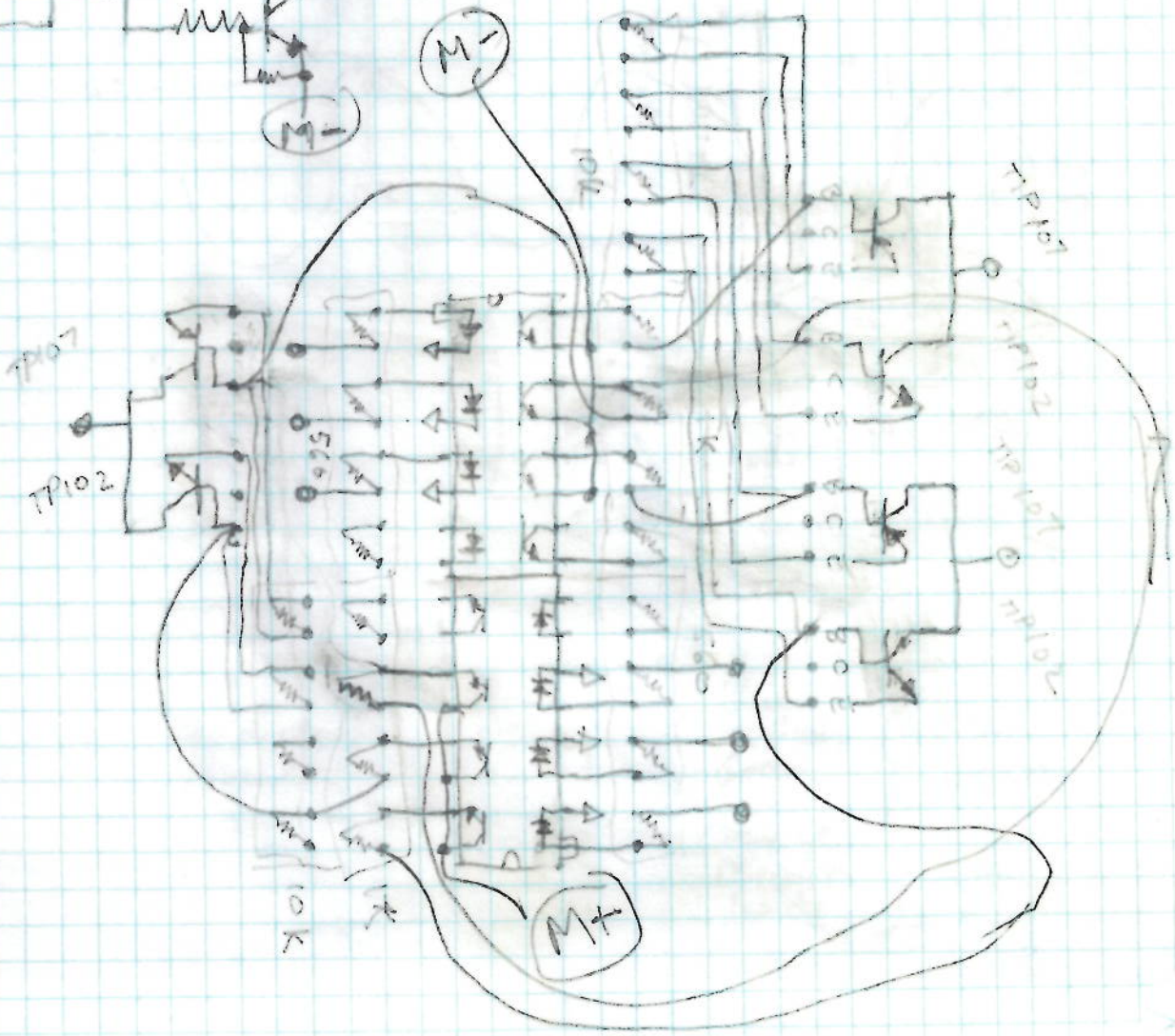
TCCR1B 10x01
gives 32 μsec period
of PWM = 31,250 Hz
next choice 10x02
gives 3,906 Hz








M+
UH, VH, WH
TP107
M-
M+
U, V, W
UL, VL, WH
TP102
M-
M-


M-
TP107
TP102
M+

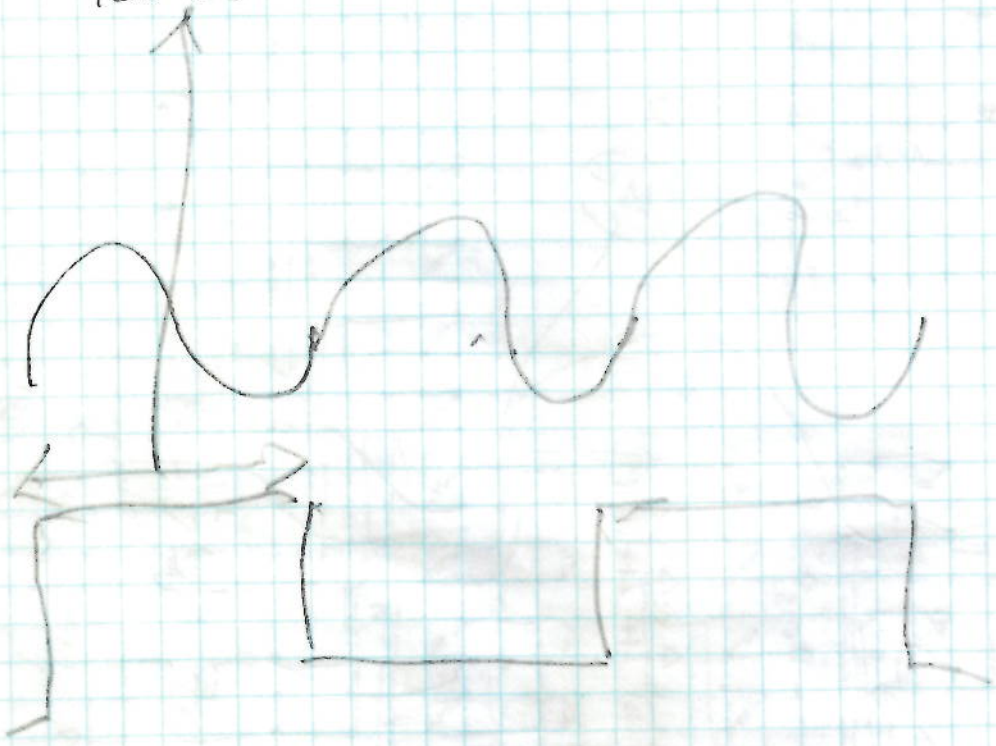
1/4 horse motor is 6 pole
673 rpm @ max

37 Hz
61%

$\frac{120 \cdot 37}{6} = 740$

$\frac{120 \cdot 60}{6} = \frac{1125}{1200}$ 3% slip

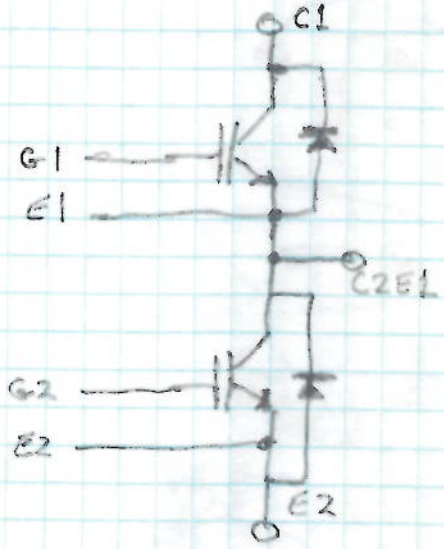
125 msec

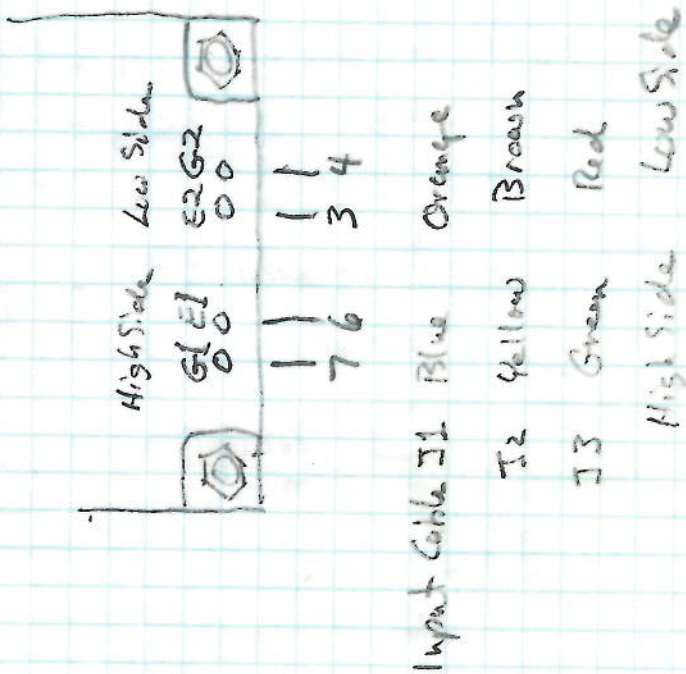


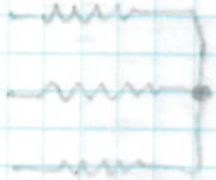
IBGT Powerex PRX

CM400DY-12H

400 Amps, 600V







1K $P = \frac{E^2}{R} = .625$ 25 50 100 W

$I = E/R = 25mA$

10K = .06 0.25

Arduino Breadboard	Green	Blue	DSP Board
	Blue	Yellow	
	Violet	Green	
	Grey	Orange	
	White	Brown	
	Black	Red	

Resolver -

Kearfott 05088 - CM06362071

7 pin connector

?? - Similar Unit

S1 Red - Green/BLK

S3 BLK - Orange/BLK

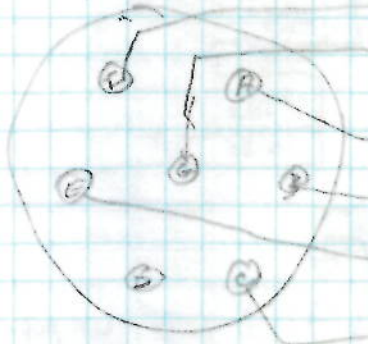
R1 Red/Wht - Red

R2 BLK/Wht - Black

S2 Yel - Orange

S4 Blue - Green

24 Ω



Cos Winding

S4

S2

$V_c = V_R \cos\theta$

R1

R2

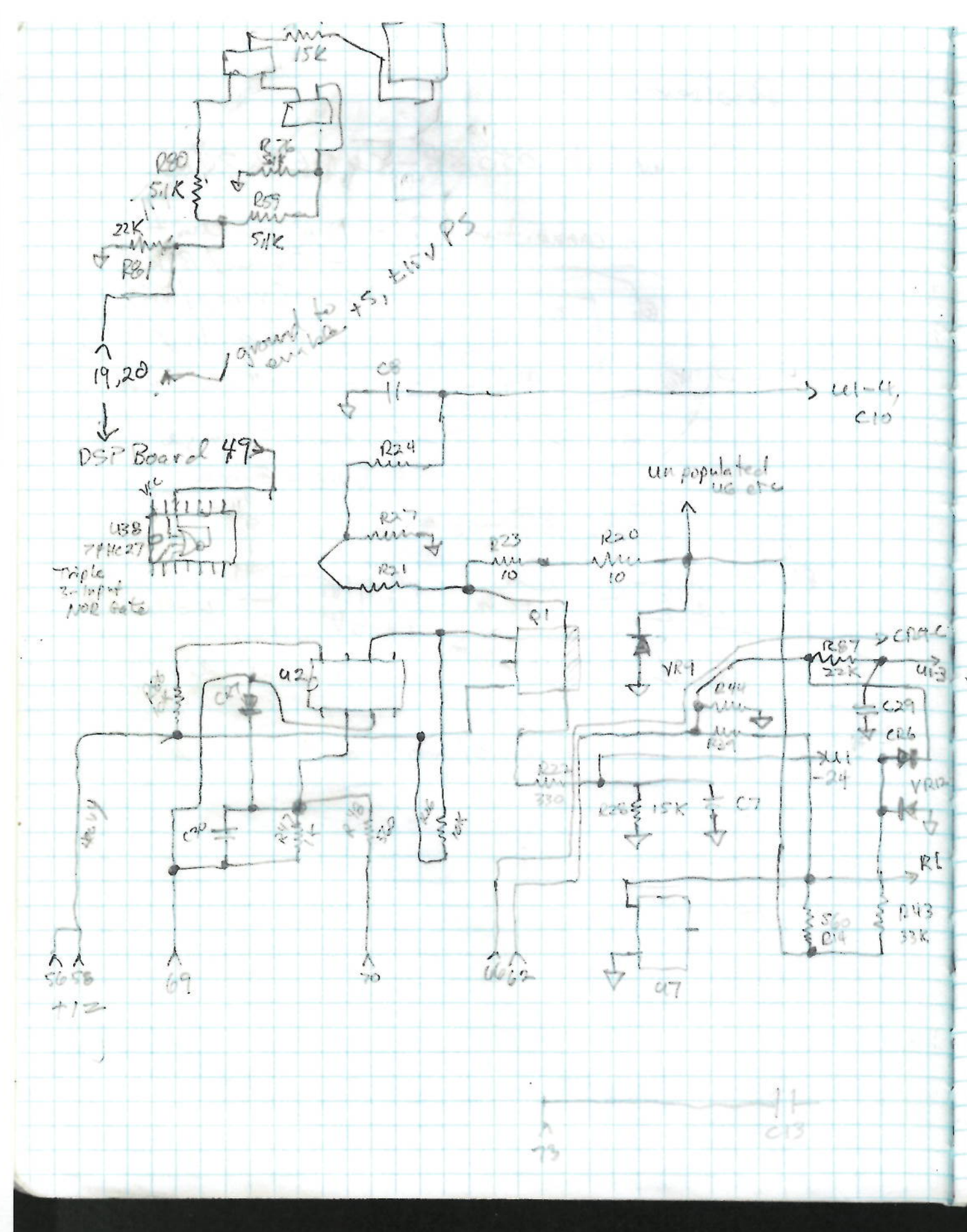
rotary Coil

θ

$V_S = V_R \sin\theta$

Sine winding

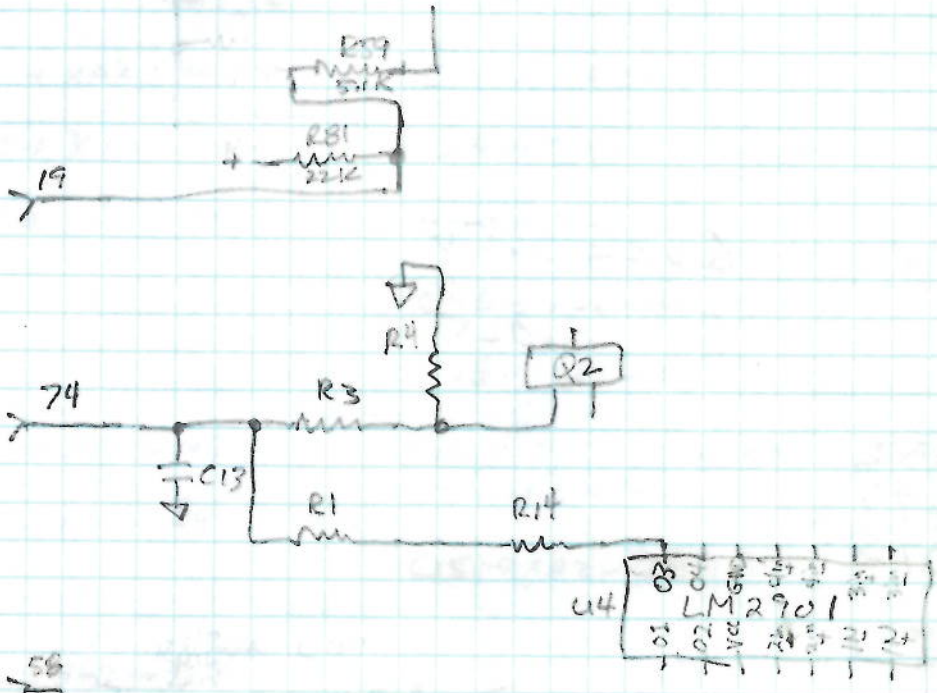
$\sin\phi / \cos\phi = \tan\theta$

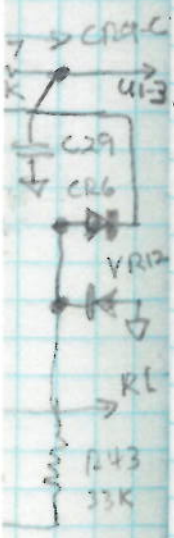

15K
R80
51K
R76
R59
51K
22K
R81
19,20
ground to avoid +5v
±15V PS
DSP Board 49
U38
74HC27
Triple 3-input NOR Gate
C8
U1-11, C10
R24
R27
R21
R23
10
R20
10
unpopulated U6 etc
Q1
Q2
C9
R44
R29
VR9
R87
22K
C29
C26
U1-24
VR12
R22
330
R26
15K
C7
R1
560
R43
33K
Q7
56 58
+12
69
70
66 62
73
C13

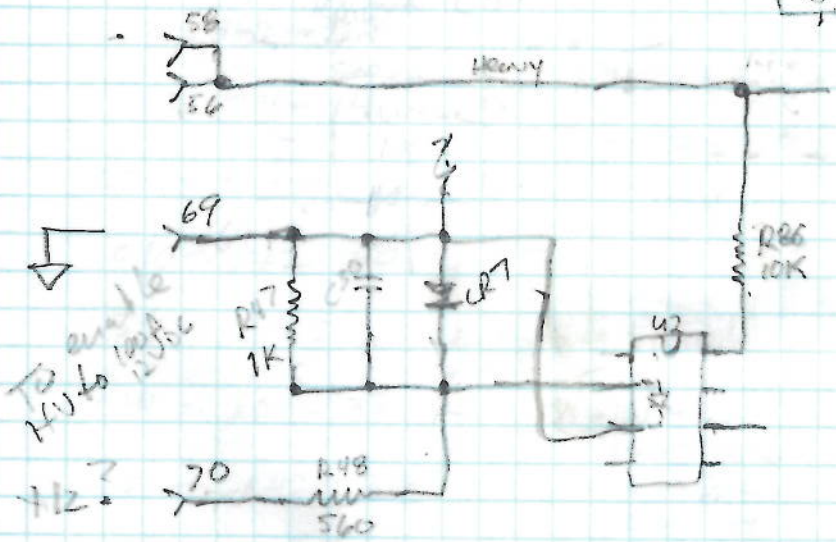
Power Control Board

P1 - 76 pin

To Main Socket: P1 - 61, 64, 69, 70







60 → CR9-C unpopulated

$E = IR$ $P = IE$

$P = I \cdot IR$

$P = I^2R$

DSP Board connector

TE Connectivity 6-532955-6

56-6

522
.483
.039

.04 V

6.0 A → 2.5 V

6. .025

2.552
2.477
.075

XA1, XA2, XA3
#1 on left, even up
J1 #1 on top

Interconnect backplane

- XA3 Numbers Right
- XA1, XA2 numbers Wrong. Pin #1 on right!

Not found C51, C10, C34, C21, C38, C22, C39, C23, C58, C59
C43, C45, C29, C49, C31, C18

C52 → XA2-90

C19 → XA3-70

C35 → XA3-64?

C20 → XA3-69

C36 → XA3-61?

C53 → XA2-87

C37 → XA2-44

C54 → XA2-93

C12 → XA2-85

C55 → J1-14

C56 → XA2-91

C40 → XA2-50

C57 → J1-5 and backplane ground

C41 → XA2-37

C24 → XA2-28

C42 → XA2-36

C25 → XA2-74

C60 → XA2-79

C44 → XA2-47

C8 → J1-9, Fan+

C27 → XA2-25

C46 → XA2-41, J1-15

C28 → XA2-17

C14, C17, C16, C48, C32 → XA3 Return
(2 pins w/o trace)

C15 → XA2-78

C9 → XA2-49

C30 → XA2-20

C50 → XA2-92

J1-16 - ?
17 → Return
18 → Return
19 → +12
20 → +12
21 → XA2-28
22 → XA2-38
23 → XA2-56
24 → XA2-77
25 → XA2-75

J1-1 → XA1-76, HV+
2 - nc
3 → XA1-72, HV-
4 - nc
5 → C57, Backplane Ground
6 → XA1-21, chassis
7 → Return, chassis
8 → Return, Fan-
9 → C8, Fan+, J1-9
10 → Return
11 - ? XA2-67
12 → +15
13 → XA2-10
14 → C55
15 → C46, XA2-41

Motor Test –

1/4 HP motor, Arduino

w/ maxFreq = 120, get 21 msec 47.6 Hz

w/ " " = 150, get 18 msec 55.5 Hz

w/ " " = 200, get 17.6 msec 56.8 Hz

300, get 16 msec 62.5 Hz.

Big Motor

@34.8 msec 28.7 Hz 830 rmp @ motor?

18.5 in Diam 600 rpm = 65 rpm at wheel in 1st gear

w/ 2" tach wheel

3.4 final drive

3.78 1st gear 12.8:1

$$830 = \frac{120 \cdot 30}{N}$$

$$\frac{1280}{360}$$

sol

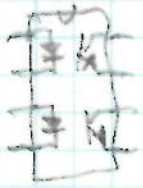
830

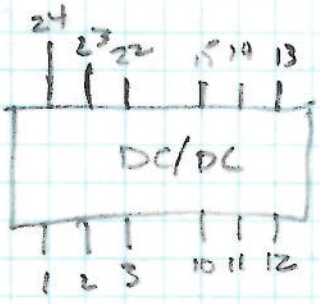
4.15 poles

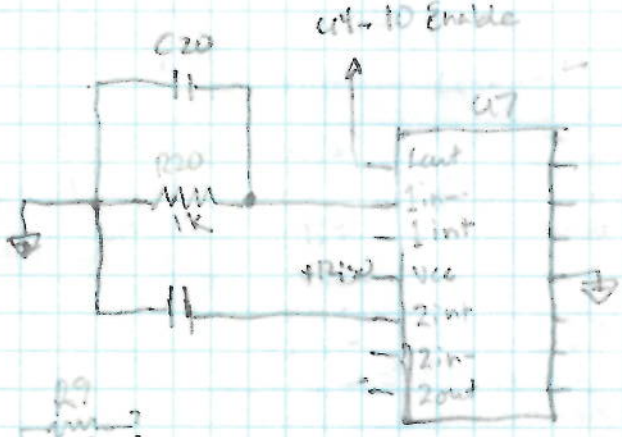
$$Hz = \frac{(5000) \cdot 4}{120}$$

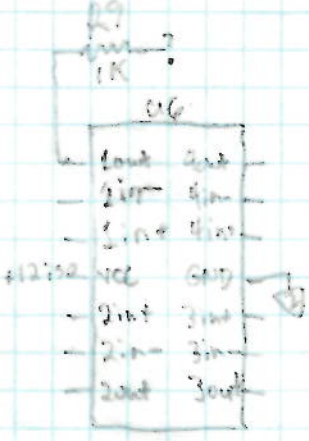
≈ 167 Hz.

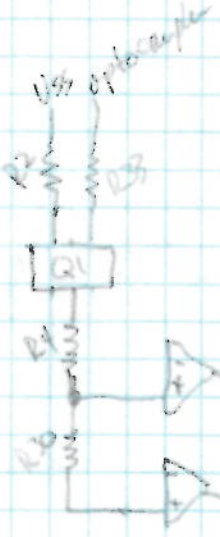
TLP621-2



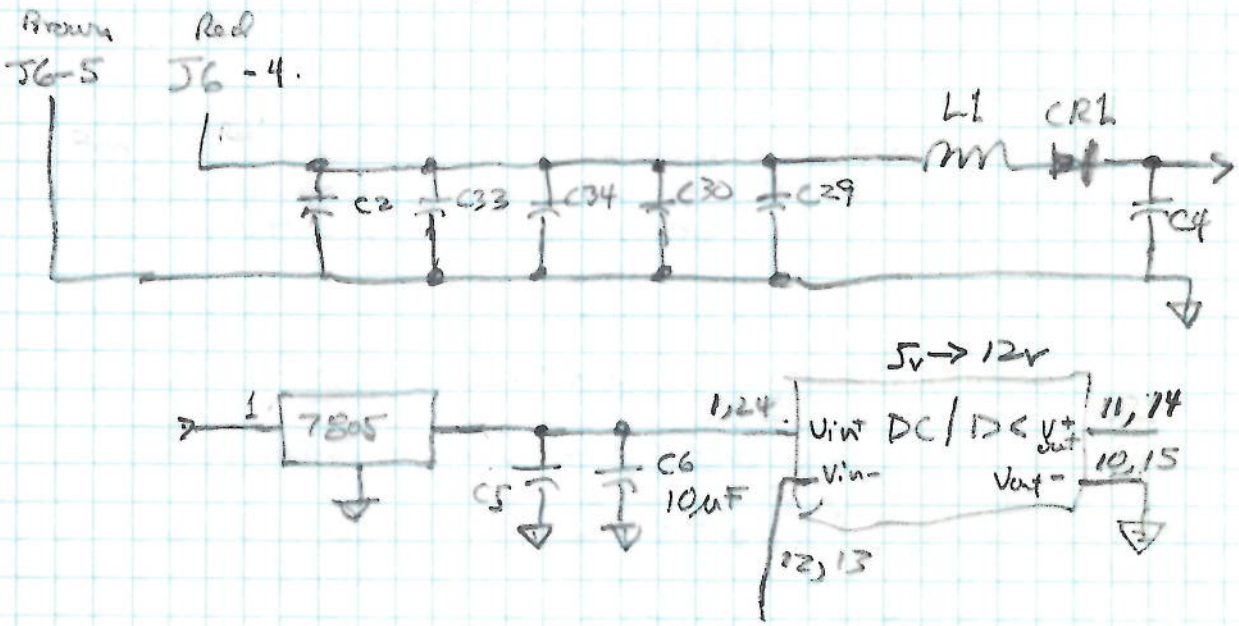

24
23
22
15
14
13
DC/DC
1
2
3
10
11
12

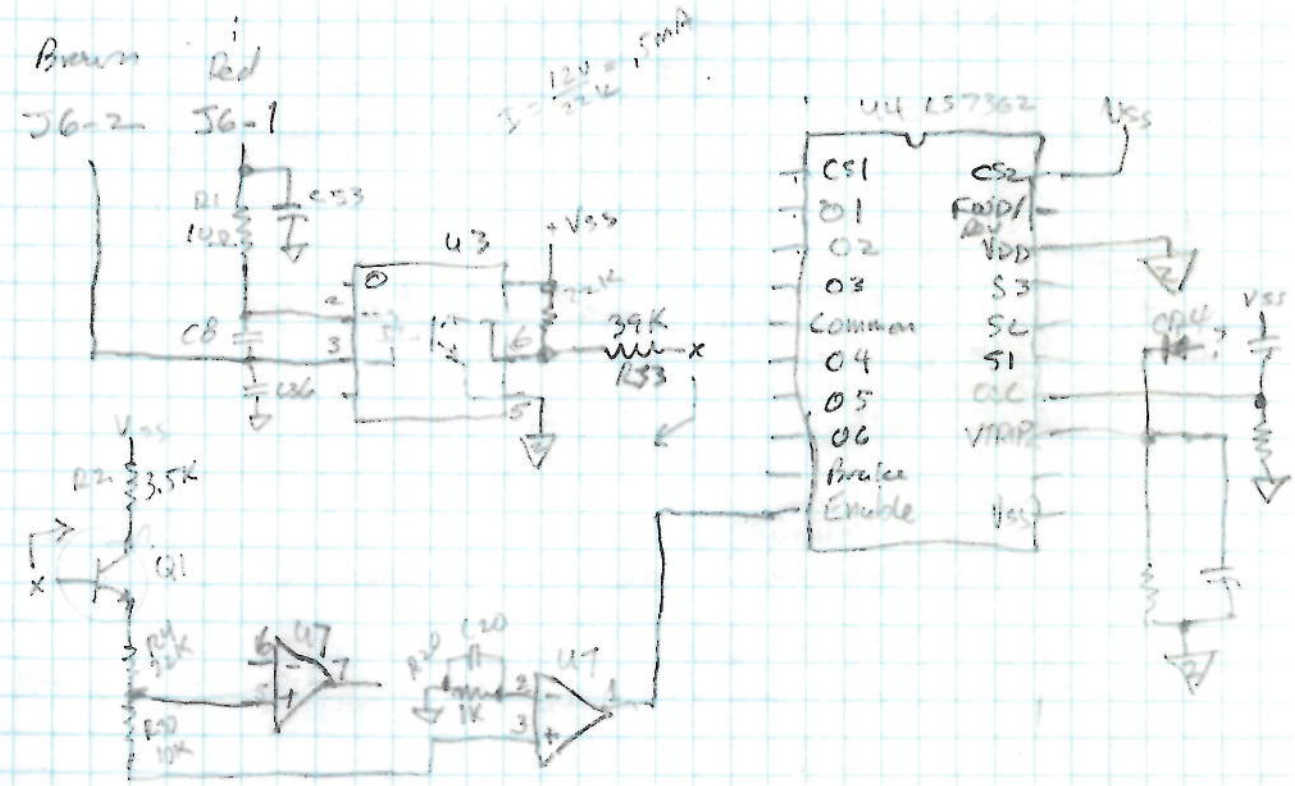

C20
CH-10 Enable
U7
R20
1K
1out
1in-
1in+
+12V
Vcc
2in+
2in-
2out


R9
1K
U6
1out
2in-
1in+
+12V
Vcc
2in+
2in-
2out
4out
4in-
4in+
GND
3in+
3in-
3out


Q1

Cooling Pump Controller





U7 = LM2902 - Quad Op Amp

Buttons

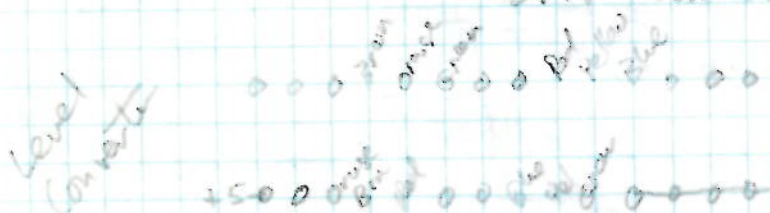
Violet	0 → 9	top	BUTTON1	J6-50	Step Page
Blue	1 → 10			J6-51	Select Page
Green	2 → 11			J6-52	Set Page
	3 → 12	bottom	BUTTON7	J6-53	

Hello Arduino

12 chars + command = 14

SCL = 14 usec 50% duty cycle ≈ 71.5 kHz

to NXP Wood Carved Version



level shift

Pin 1x	NXP	DSP Brd	Level Shift Pin Out
21	Brn	Org	3
20	Org	Brown	4
19	Green	Red	5
16	Red	Blue	8
15	Yellow	Yellow	9
14	Blue	Green	10

Upside Down
Pin Locations

LCD Display

			Doug's	
1 - RST	- Blue		Violet	J6-4
2 - SCL	- Yellow		Gray	J6-26
3 - SDA	- White		Violet	J6-25
4 - VSS	- GND	- Green	Green	J6-54
5 - VDD	- +3.3	- Orange	Gray	J6-28

6 - VOUT - Cap to VSS or VDD
7 ⎫
8 ⎭ CAP

I2C

PIO 4.27 SDA J6-25
PIO 4.28 SCL J6-26

NXP Connections

per drawing

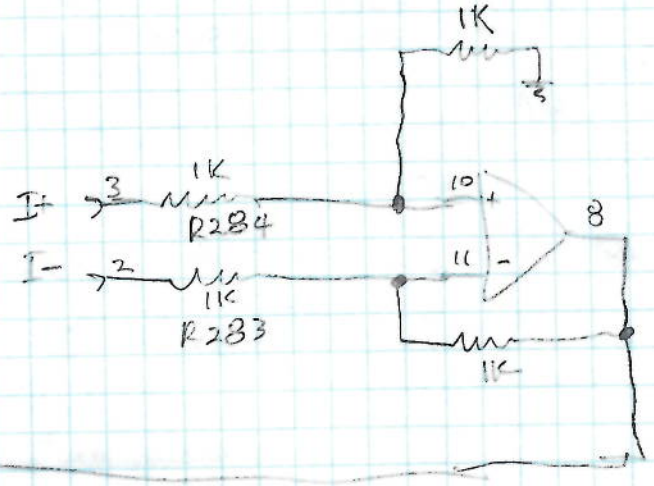
		Pulse Out @ 3m	"Side"	NXP	DSP Brd
MC0A -	PAD 2	Mostly Hi	Low	Brn	Or
MC0B -	PAD 5	" Lo	High	Red	Blu
MC1A -	PAD 3	Mostly Hi	Low	Org	Brown
MC1B -	PAD 9	Mostly Lo	High	Yellow	Yellow
MC2A -	PAD 11	Mostly Hi	Low	Green	Red
MC2B -	PAD 12	" Lo	High	Blue	Green

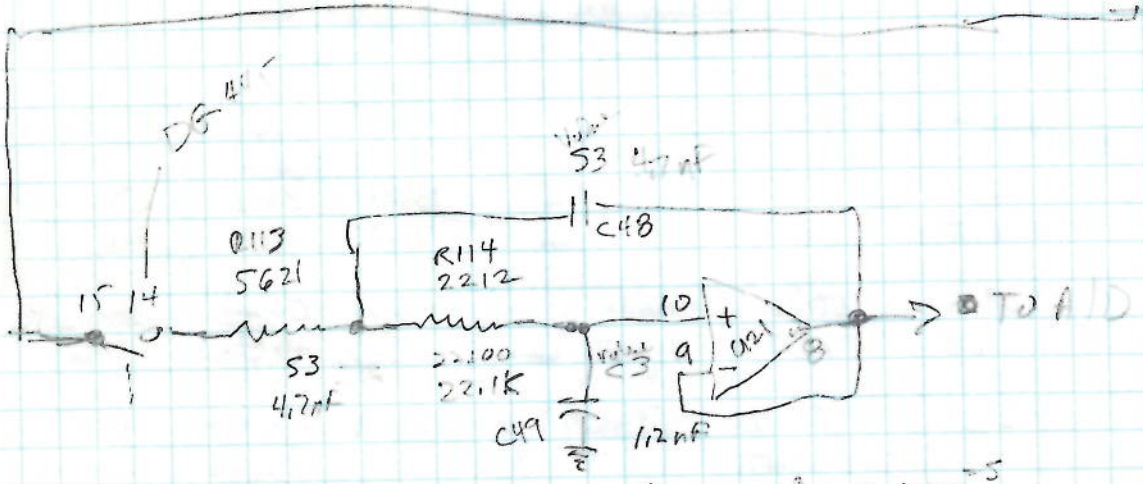
Resolver Standard Color Code

	R/W - Exc +	Red	Cos +	Yellow	Sin +
Blk/y ← or	Blk/W - Exc -	Black	Cos -	Blue	Sin -

w = a1

New A/D MCP3008 10 bit
3208 12 bit





$2.2\times10^{4} \times 1.2\times10^{-9} = 2.6\times10^{-5}$

$= 26\,\mu sec$

$\approx 40\,kHz$

Current Sensors

LEM - HAL600 - S/SP2 ±15V in

±4V out ⟺ ±600A
on Pin 3
Pin 4 ⏚

Voltage Sensor

LEM LV 20-P

Alternate I sensor LEM HASS 600 5V
HAS 600 ±15V

Current Sensor Plug

Pin (wrt board etch)

1
2
3
4
5 +5
6 GND
7

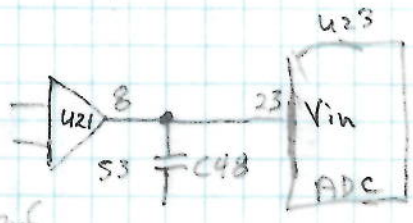
	Volts	A	+15 PS only
per marking	2.490	0	
	2.511	5	+0.02
	2.591	25.6 A	
reverse	2.470	5	-0.02

0.04 V / 10 Amps.

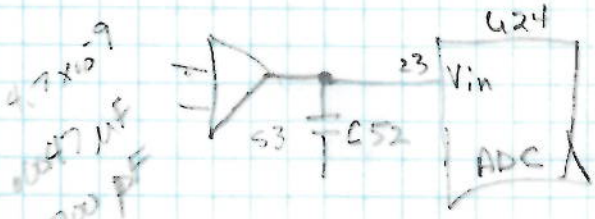
4mV/amp × 14.2

.0568 V rms

.159 V p-p



53 = 4.7nf



4.7×10^{-9}

4700 pF

4mV/amp × 300amp =
1200 mv = 1.2V

	2.59	2.5
	+1.2	-1.2
+300A →	3.7V	1.3V
-300A		

T108

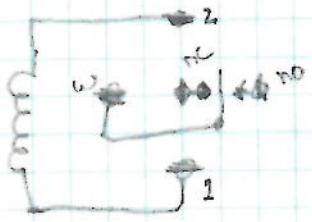
Aromat Relay

C B 1 F - P - 12V

Form C — Fuse Bracket — PC board — Coil

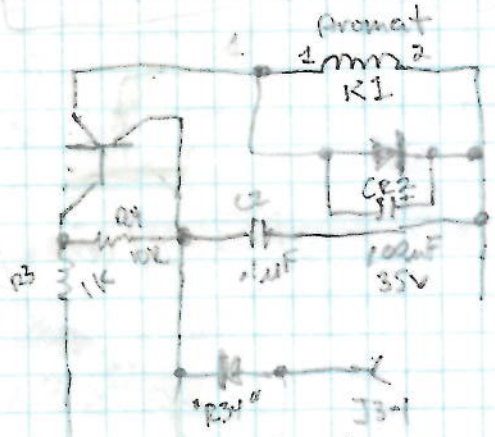
Mounting plate

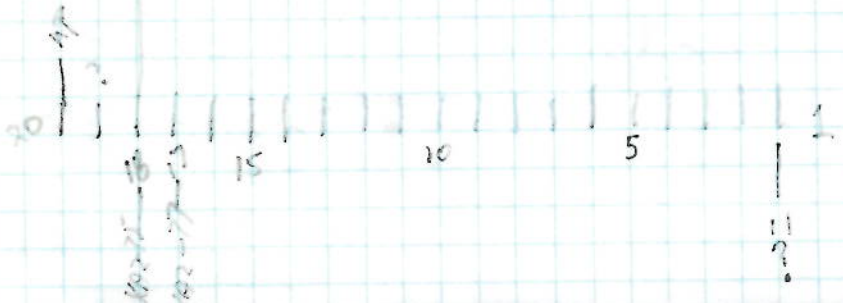
Front Label



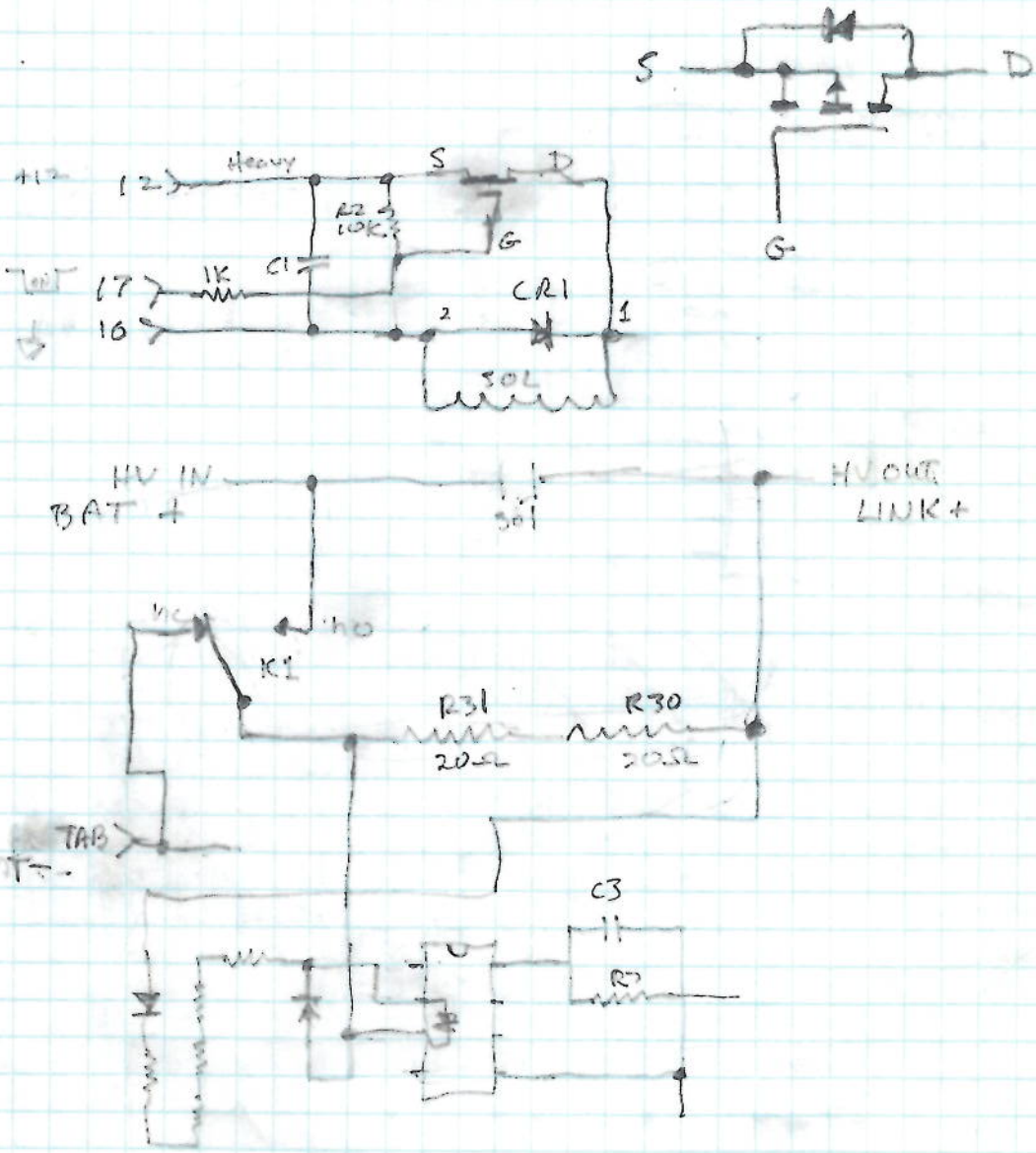
J3 - switch on fuse panel

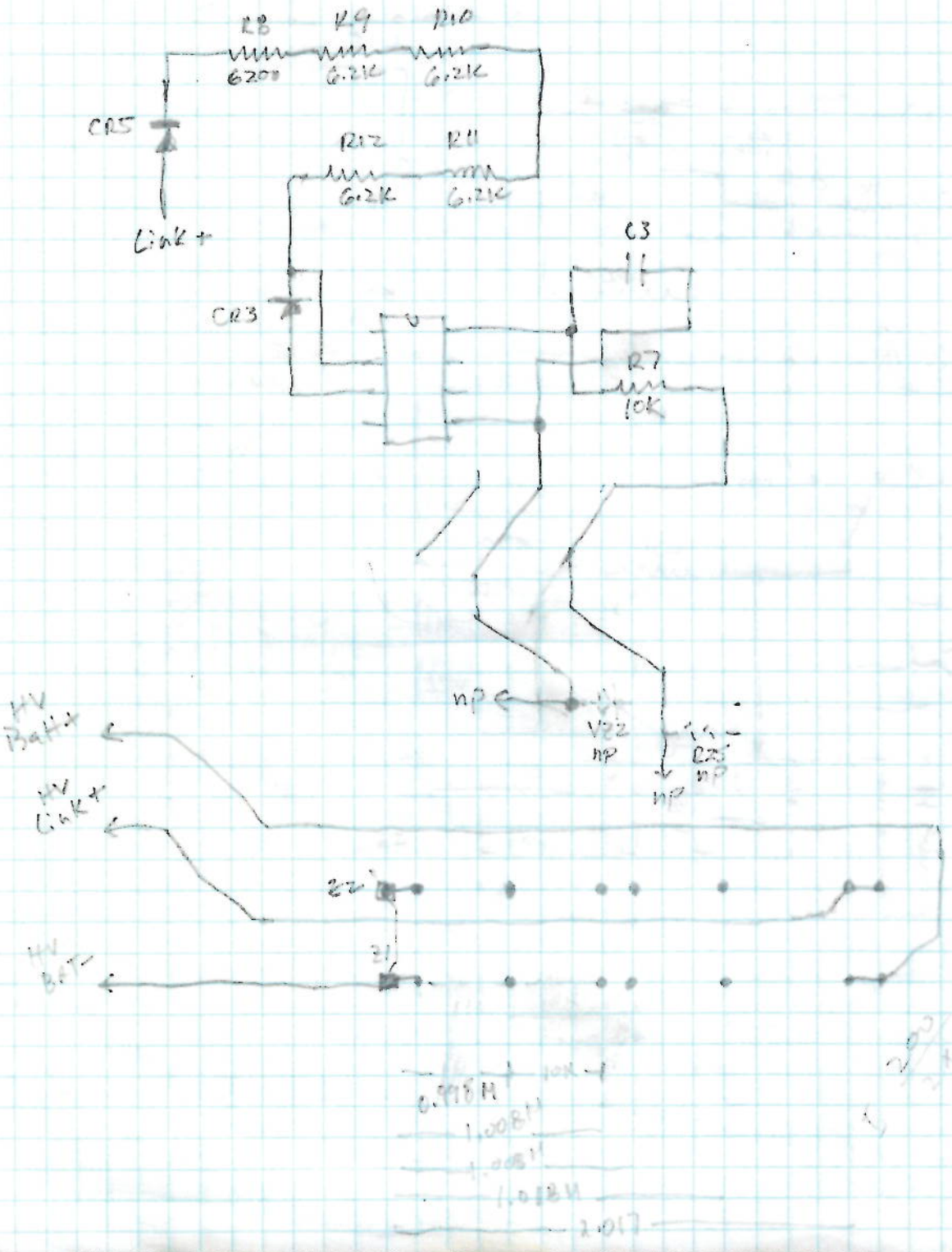
J2 - Main H.V. battery (link or connector?)

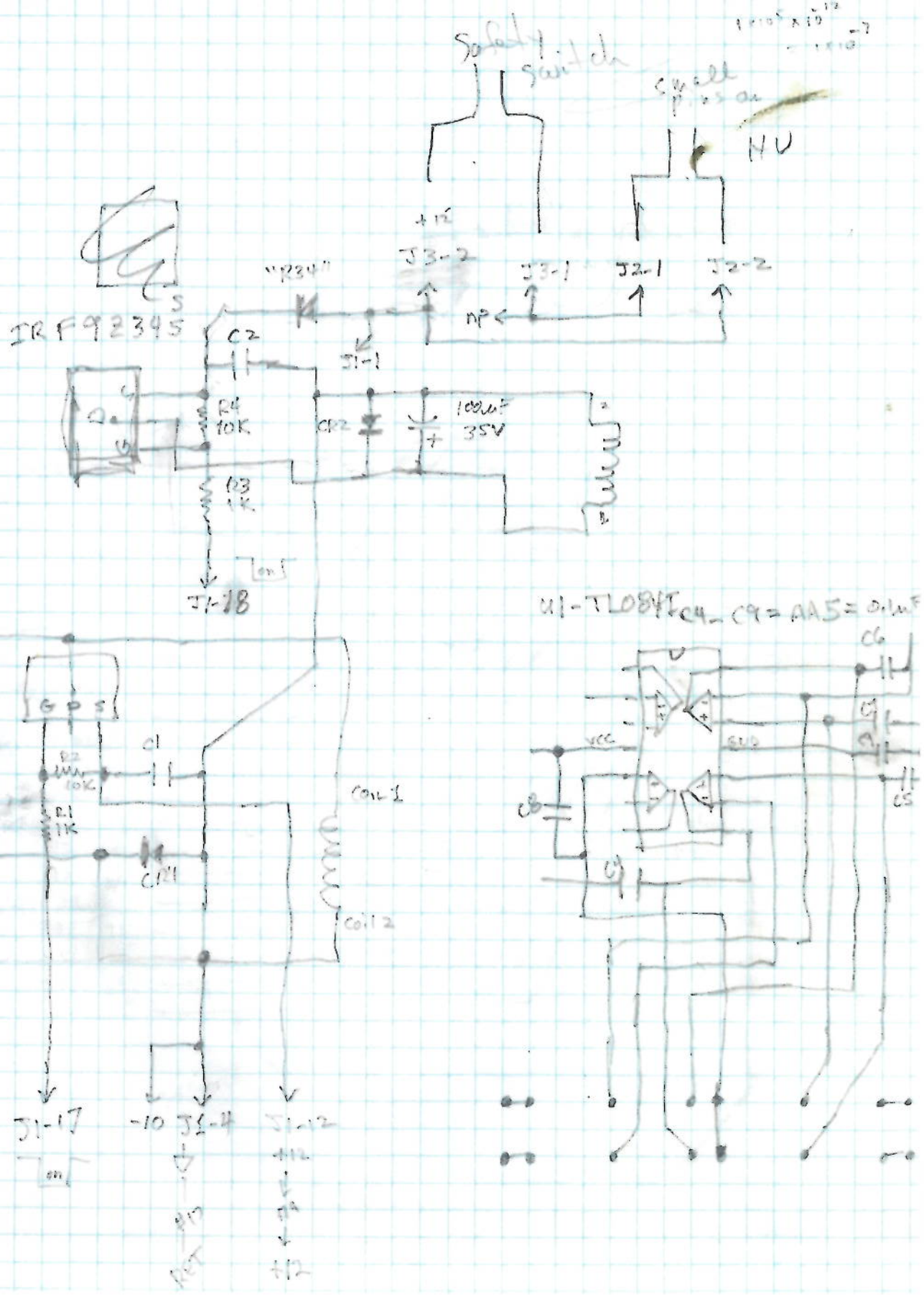




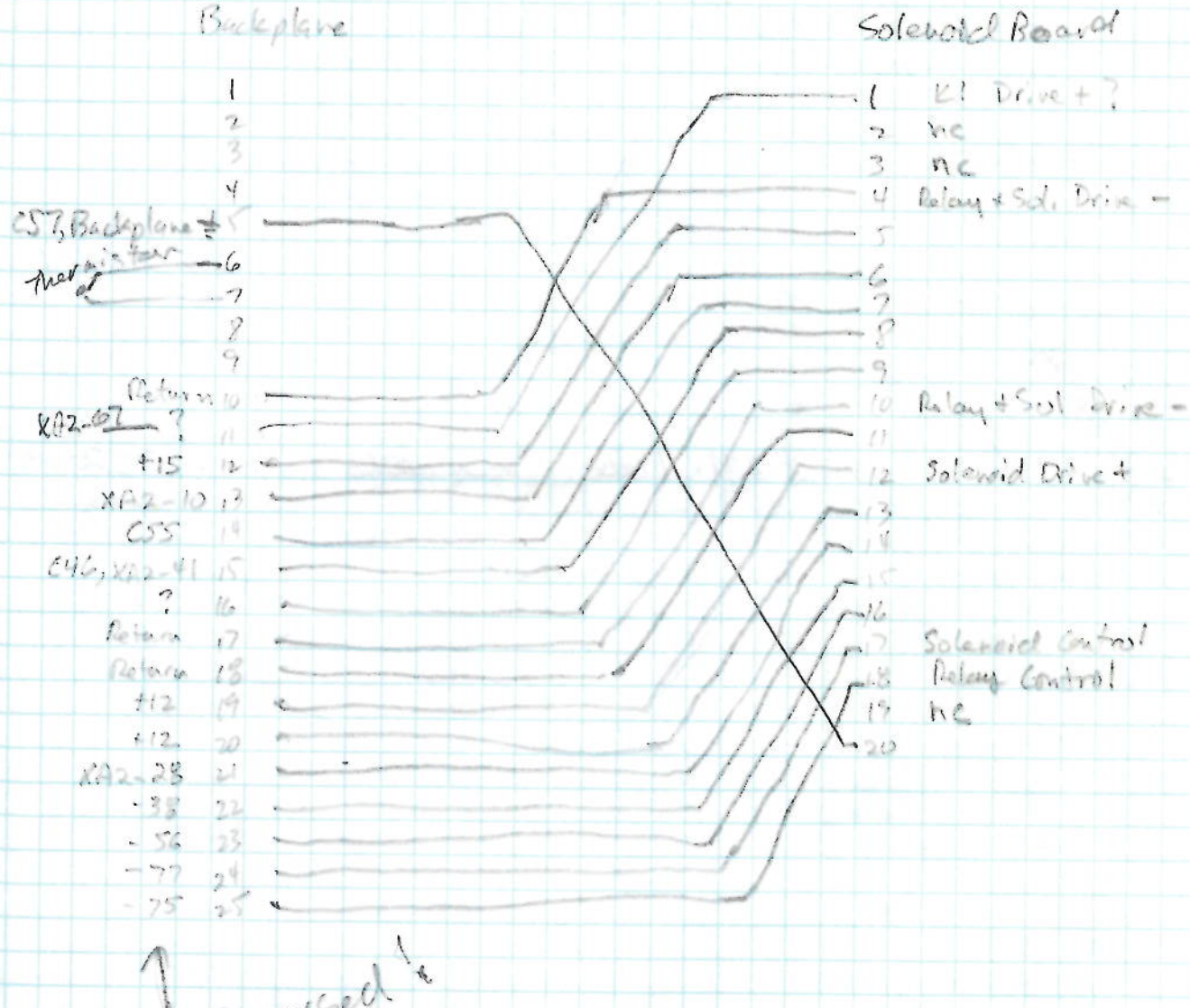
Solenoid Board

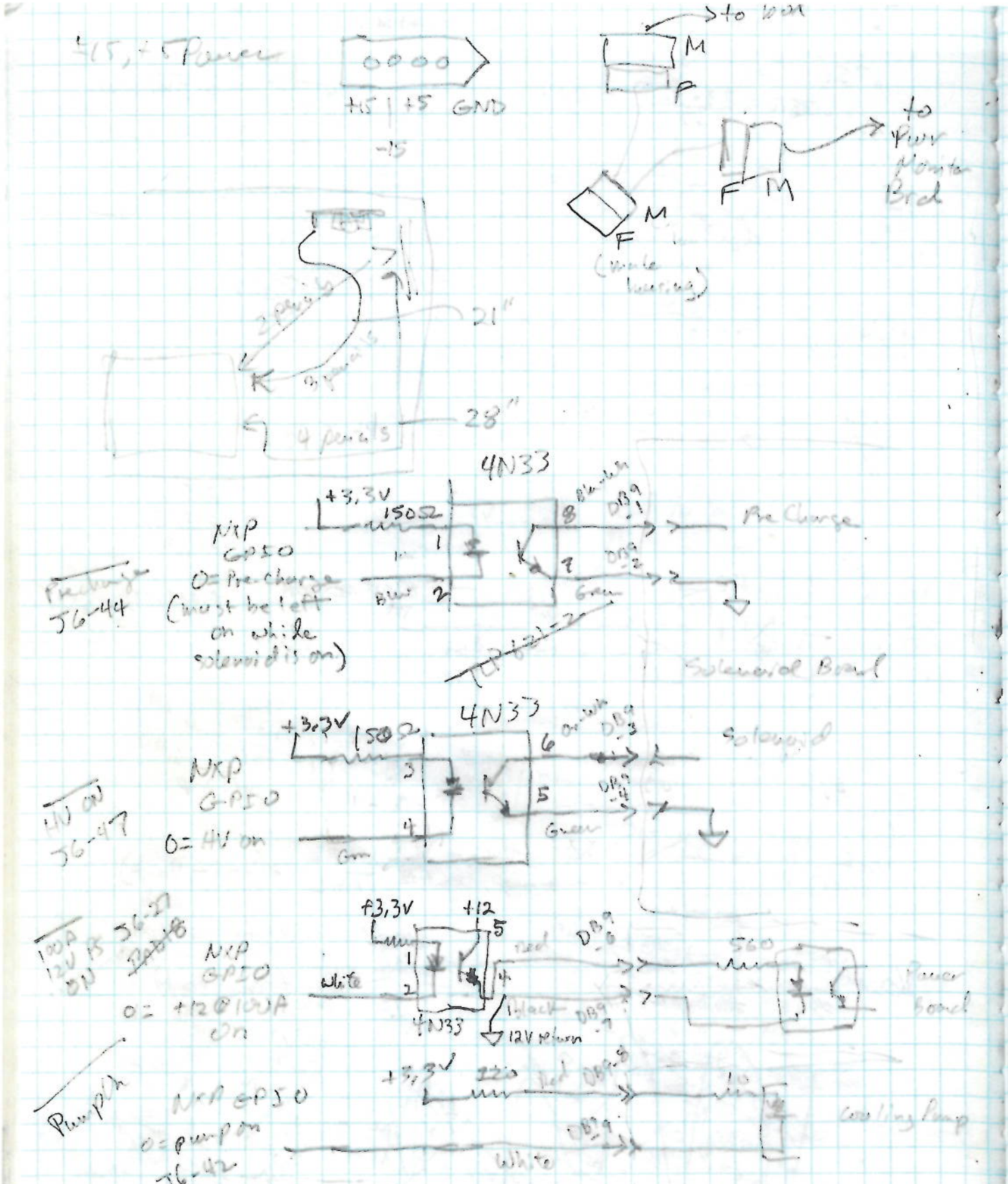



R8
R9
R10
620Ω
6.2K
6.2K
CR5
R12
R11
6.2K
6.2K
Link +
C3
CR3
R7
10K
np
V22
np
R23
np
np
HV Bat+
HV Link+
22
21
HV Bat-


Safety switch
HV
+12
J3-2
J3-1
J2-1
J2-2
"R34"
IRF92345
C2
J1-1
R4 10K
CR2
100uF 35V
R3 1K
J1-18
U1-TL084
C4 - C9 = AA5 = 0.1uF
C6
VCC
GND
C8
C5
R2 10K
R1 1K
C1
CR1
Coil 1
Coil 2
J1-17
-10
J1-4
J1-12
+12

Solenoid Board to Backplane cable



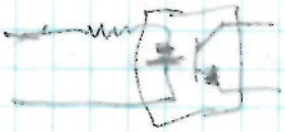

+15, +5 Power
+15 | +5 GND
-15
to Pwr Monitor Brd
(Male housing)
21"
28"
4 pencils
4N33
+3.3V
1502
NXP GPIO
0=Pre-charge (must be left on while solenoid is on)
Blue
Green
Pre Charge
Solenoid Board
Precharge J6-44
4N33
+3.3V
150Ω
NXP GPIO
0= HV on
Green
Solenoid
HV on J6-47
+3.3V
+12
NXP GPIO
0= +12@10mA on
White
Red
Black
12V return
560
Power Board
100A 12V PS J6-27 ON
Pump
NXP GPIO
0= pump on
J6-42
+3.3V
220
Red
White
Cooling Pump

to Power Monitor Brd

NKP control of Power Circuits, Interlocks

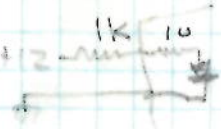
(PAD-19) (PAD-17) +5, ±15 P.S. (just a switch-) single wire to common

PAD-49 Fan → switched 12V dc or opto?

PAD-13 100A 12V PS →  O/to

PAD-13 GPIO IGBT cables on ← sense link continuity

MC 1/10 Fast Abort ← active low from Power Monitor Brd
PAD-14 Jump to PAD-4 P1-2

J6-42 Cooling Pump En → optocoupler LED = or equal 

J6-42 Pump Power → HVDC from fuse

J6-44 Pre Charge Relay → ground J1-13 if J1-1 is +12 (11K to +12)

AI(3) J6-18 Temperature ←

J6-47 HV Solenoid → ground J1-17 if J1-12 is +12 (11K to +12)

Power Board

AI(1) J6-16 AI HV voltage ← analog 0-330 V = 0-3.3V P1-1

ing Pump

AI(2) J6-17 AI HV Current ← analog 0-330A = 0-3.3V P1-3

J6-43 GPIO Oil Sense ← Switch Closure

10/2/13

IT WORKS !!

First test run @ 4:32pm

30 yards in 1st gear,
33 yards in reverse,
then up the driveway 35 yards
to parked in garage!

To Do:

1. connect up Batt Volts + temps to NXP
2. connect up discrete I/O to NXP
   - P.S. board enable latch
   - Cooling Fan (S/W)
   - Pump 12V power on/off
   - Pump enable on/off
   - DC/DC (12V 100amp) on/off
   - Pre-charge on/off
   - Main HV on/off
   - Oil pressure on/off
3. finish temperature probe + connect to NXP

Nice charger would be 400V @ 10 amps

Charging Balance Circuit

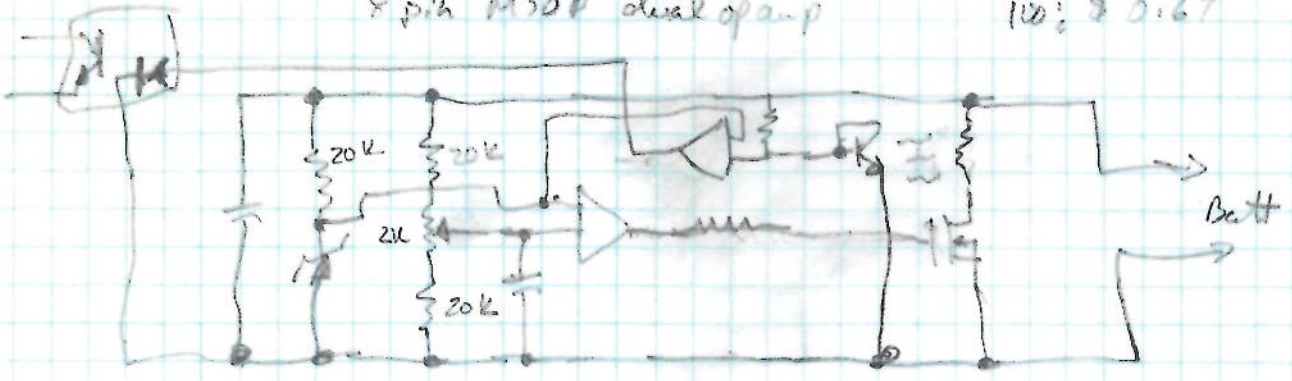
PIC12F683 based Mouser 1: $1.42
25: $1.15
100: $1.12

7 Resistors 20K, 2K, 1K, 1K, 40M, 470, 20K
1 2N2222
1 IRL520
1 LM336-2.5
1 2k pot
1 1Ω R
2 Caps 100nf · 0.1uF
1 - Optocoupler (abort output)
1 - LED
2 - Connectors

• less resistors + caps $6.80/1
$465.80/100
$57.13/10

Analog Design

Seiko S-8943x A/B series
S8431BCFN-HEVTF 1k Mouser 1: $0.74
8 pin MSOP dual op amp 100: $0.67



~~IGBT Conduction losses~~

$$\cancel{P_{cr} = v_{CO} \cdot I_0 \cdot \left(\frac{1}{2\pi} + \frac{m \cos\theta}{8}\right) + r_c \cdot I_0^2 \cdot \left(\frac{1}{8} + \frac{m}{3\pi}\right)}$$

IGBT Gate Drive

Powerex BP6A-L Series drives need 1 ~$210 +.

PM450LA060 450A @ 600V $450 passive pwr

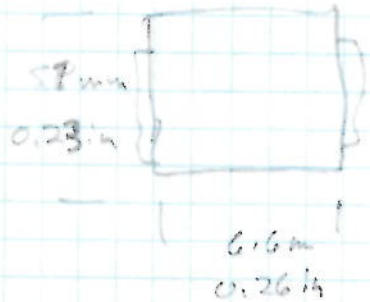
(BP6A fits on drive pins of IPM)

Powerex VLA500-01 DC/DC + gate driver $45

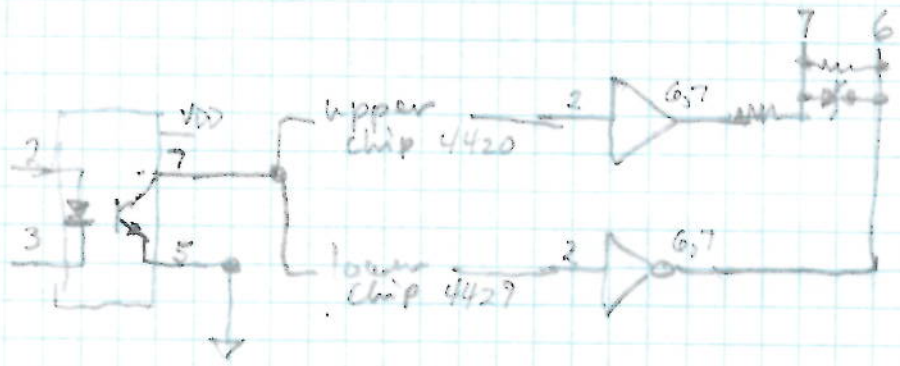
BP2A - dual driver - need 3

BG2B-5015 dual driver + isol. pwr 15V.

1N4745 16V Zener



Drivers In = 2,3
Out = 6,7
Vdd = 1,8
Gnd = 4,5



1/8

1	2	3	4	5	6
✓	✓	✓	✓	✓	✓
			Gnd		
			✓		

Driver Board Test 10/14/2013

J1-7

	Left Q1	Right	1st Q2	Right	Left Q3	Right
Opto Out # 7	L	L	L	L	L	L
Inv. Driver #6,7	H	H	L	Lv	H	L
Non-Inv. Dr. #6,7	L	L	L?	H	L	L

2,3
6,7
1,8
4,5

① ② ③ v = variable ⑤ ⑥

Pulse Test

upper ✓ ✓ J1 ✗ ✗ ✓ ✗ lower J2 ✗ ✗ ✓ ✓ J3 ✗ ✗

-7 -6 -4 -3 -7 -6 -4 -3 -7 -6 -4 -3

Input Opto-2

Output

Opto

Upper

Lower

Pass - all opto inputs OK

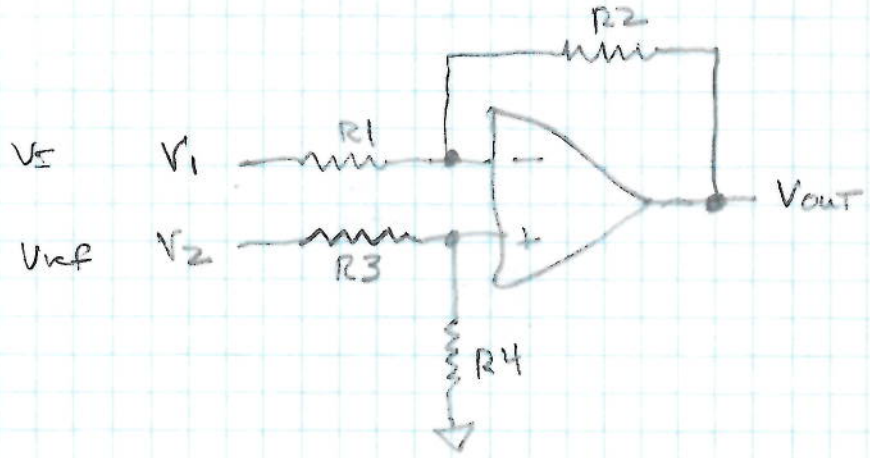
Repair - opto output 1=OK, 2 , 3=OK, 4,5,6=OK

		1	2	3	4	5	6
(lead) lower chip	in	✓	—	✓	✓	✓	✓
(pad) " "	out	✓	—	✓	✓*	✓	✓
(lead) upper chip	in	✓	—	✓	✓	✓	✓
(pad) " "	out	✓	—	✓	✓	✓	✓
J-1		✓	✗	✓	✗	✓	✗

*gnd offset

$y_1 = ax_1 + b$

$y_2 = ax_2 + b$



$$V_{out} = \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R4}{R1} V2 - \frac{R2}{R1} V1$$

For $R1 = R3$ + $R2 = R4$

$$V_{out} = \frac{R2}{R1}(V_2 - V1)$$

$$V_0 = \left(\frac{100k + R2}{100k + R4}\right)\frac{R4}{100k} \cdot V2 - \frac{R2}{100k} \cdot V1$$

$$V_0 = \frac{V2 \cdot R4 \cdot (100k + R2)}{100k \cdot (100k + R4)} - \frac{R2 \cdot V1}{100k} \cdot \frac{(100k + R2)}{(100k + R2)}$$

$$V_0 = \frac{V2 \cdot R4 \cdot (100k + R2) - R2 \cdot V1 (100k + R2)}{100k \cdot (100k + R4)}$$

$$V_0 \cdot 100k \cdot (100k + R4) = V2 \cdot R4 \cdot (100k + R2) - R2 \cdot V1 (100k + R2)$$

$$100k + R4 = V2 \cdot R4 \cdot (100k + R2) - R2 \cdot V1 (100k + R2)$$

$$R4 \cdot 100k + V2 \cdot R4 (100k + R2) - R2 \cdot V1 (100k + R2)$$

$$R4 = 100k + 100k \cdot V2 \cdot R4 + V2 \cdot R4 \cdot R2 - 100k \cdot R2 \cdot V1 + R2^2 \cdot V1$$

2.5
.625
3.125

2.500
− .625
1.875

8920
1175

$y = ax + b$

2.5 ± 0.625

+400A → 3.125
0 A → 2.5
−400 A → 1.875

New Circuit Test

Vref = 2.537

Vin	2.020	2.656
Vout	3.29	0.208
ΔVin	+0.517 V	+0.119
	−331A	76 A 0A

w/2.5ref

331
76
407

0 − .625

2.5
.517
3.017

407A

3.29
− .21
3.08

.119
2.5
2.62

.46875

.517
.625

656
537
.119
.625

132 mV

300	3	2.25	3.00
0	0	0	0.75
−100	−1	−0.75	0.00
−300	−3	−2.25	

640A/V

.119 V

$K(V_1 - V_2)$

$K(V_1 - V_2)$ (V_1: 3.125, 1.875)

3
.625

1.825

4.8 (3.125 − 1.52, 1.875)

4.8 (2.5, 0) = 3, 0

(R1+R2)/(R3+R4) = 1.06
R4/R1 = 5
R2/R1 = 5

R4 = 5R1
R2 = 5 R1

(G.1 + 5R1) = 1.06 (R3 + 5R1)

6R1 = 1.06 R3 + 5R1
1.06R3 = 6R1 − 5.3R1
R3 = .66R1
R2 = 5R1
R4 = 5R1

1.06
5.30

.7 R1
1.06

Resolver to QEI 3½" x 3" x 3/8" or 1/2" or 1"

↓ No conn. ↓ Female conn ↓ complete conn

Connector

90 Sq. Flange Receptacle

94 Single Hole Receptacle

96 Cable Mount Plug

Durr 319

318 available

or 1"
↓
complete
conn

Large Connector

S6009-23-5351 Deutsch 11139 9628A

53 #20 Contacts Box is Female

Insert 23-53

				Qty
Arrow	D38999/26WA53PB	Conn ~~$51.20~~	$52.87	1
11/29/13	M39029/58-363	Pin	$0.1845	57

$63.39
+ Tax 3.81
+ Ship 8.00
$75.20

Ref # IC 0-060412

2N4403 PNP

1 = E
2 = B
3 = C

2N4401 NPN

60V
600mA
625 mV
hFE ~100

Small Connector

Plug - DG123AGR11-99PL-6152

11139 9639B

1/1/14 CAN Bus Test

			MCP2551 Xceiver
CAN1	P0.0 = RD1 =	J6-9	Pin 4
	P0.1 = TD1 =	J6-10	Pin 1
CAN2	P2.7 = RD2 =	J6-49	Pin 4
	P2.8 = TD2 =	J6-50	Pin 1

RD-TD, 1K Test - AOK

→ ← 8usec

Self Receive through Xceiver AOK -

R_s = 38K

CAN1-CAN2 loop test - AOK

Invert Park per the paper

$V_a = V_\beta$

$V_b = \frac{1}{2} V_\beta - \frac{\sqrt{3}}{2} V_\alpha$

$V_c = -(V_a + V_b)$

$V_c = -V_a - \frac{1}{2} V_\beta + \frac{\sqrt{3}}{2} V_\alpha$

$= -\frac{3}{2} V_\beta + \frac{\sqrt{3}}{2} V_\alpha$

2*03

per MS code

$V_a = V_\beta$

$V_b = -\frac{1}{2} V_\beta + \frac{\sqrt{3}}{2} V_\alpha$

$V_c = -\frac{1}{2} V_\beta - \frac{\sqrt{3}}{2} V_\alpha$

check w/ MS, but α, β reversed another not reversed

2π = 6434

2 • Pi << 16 / 0x3 << 4

return int16_t(Amplitude • $\frac{2\pi << 16}{0x3 << 4}$) >> 16

VMC_LIB_SetPWM_FG_10

AH = ((12000/2) • (1024 − A.full)) / 1024

6000 • (400) / 1024

24

A full = 0 ⇒ AH = 6000

A full = 1024 ⇒ AH = 0

Per Paper

$AH = (\text{Period}/2) \cdot A + \frac{\text{Period}}{2}$

Our V/F was 0-900 so value to based PWM

Vq	Vd	100k - 10^{-4} pF Sinewave p-p	Pulse (Period - Pulse)
10K	0	400 mV	
10K	10K	580 mV	
60K	60K	350 mV	20 - 30
60K	0	220 mV	22 - 30

Current $10^{-2} \times 10^{-6} = 10^{-8} \times 22 \times 10^{3} = 22 \times 10^{-5} = 2.2 \times 10^{-4} = 220\,\mu sec$

2.2 μsec $RC = 0.01\,\mu F \cdot 22K$

10000×10^{-12} 10^{-8} 22×10^{3}

$22\ 10^{-5}$

Simple FOC Test

"Fan" = PAD 19 MCABORT/ = PAD 4

10 kHz = 100 μsec per execution (step)

for freq of 100 Hz period = 10 msec

10 msec ÷ 100 μsec = 100 steps per cycle

need to increment ~~alpha(a)~~ alpha by $2\pi/100$

MCOA = PAB 2
0B 5
1A = 8
1B = 9
2A = 11
2B = 12

Vd, full = 0	alpha	Scale	Valph	Vbeta	Vr1	Vr2	Vr3	A	B	C
Vq, full = 10000	1		-625	9980	311	-173	-140	445	668	355
64					~~Vr not scaled by 32~~		wrong			
128	1		-1250	9992	310	-189	-122	478	667	356
192	1		-1865	9824	307	-204	-104	462	666	358
256	1		-2471	9688	302	-219	-85	445	664	360
320	1		-3076	9512	297	-232	-66	429	661	363
384	1		-3662	9307	290	-245	-47	410	658	366
3584	4		3516	-9365	-293	241	51	607	366	658

After new program routine w/ Vq = 10000, Vd = 0
get 3 phase sine wave ≈ 400 mV p-p centered 2.1V
w/ Vq = 10,000 ; Vd = 10,000 580 mV p-p " "

Thermister Test

$0^\circ C$ $32^\circ F$ = 3237 KΩ

$125^\circ F$ = 3.07 KΩ

60°F ≈ 15.13

~90° ≈ 194°F = 720 Ω

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{B}\ln\left(\frac{R}{R_0}\right)$$

$T_0 = 25^\circ C \rightarrow 298.15 K$

$R_0 = 10K$

B = 3950 (for Adafruit Th)

$$R = R_0 e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

for $T = 0^\circ C = 273^\circ K$

$$R = 10K \cdot e^{B\left(\frac{1}{273} - \frac{1}{298}\right)}$$

.003663 − .003356

.0003073

1.214

3.366

R = 33.7 K

for T = 125°F = 52°C = 325°K

R = 3.3 K

4.00 Ω/°C

62°F = 16.7°C

2.5°C / 1.7°C / 3°C

4.50 Ω × 8 = 3.6 K

1.7 / 3.6 / 10.2 K

More
FOC Test

5.0	+600
2.5 *	0
0	-600

$\frac{5V}{1200A} = 4.167 \frac{mV}{A}$

~~2200~~

4095 counts = 285 Amps

2775 counts = 0 amps

0 counts = -600 A

so +600A = 2775 + 2775 = 5550 counts

600A / 2775 counts = 0.216 A/count ; 4.625 counts/amp

4095 counts - 2775 counts = 1320 counts × 0.216 A/count

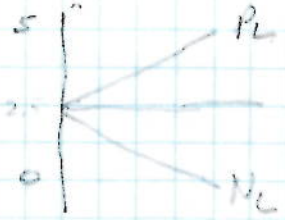
= 285 amp Fs.

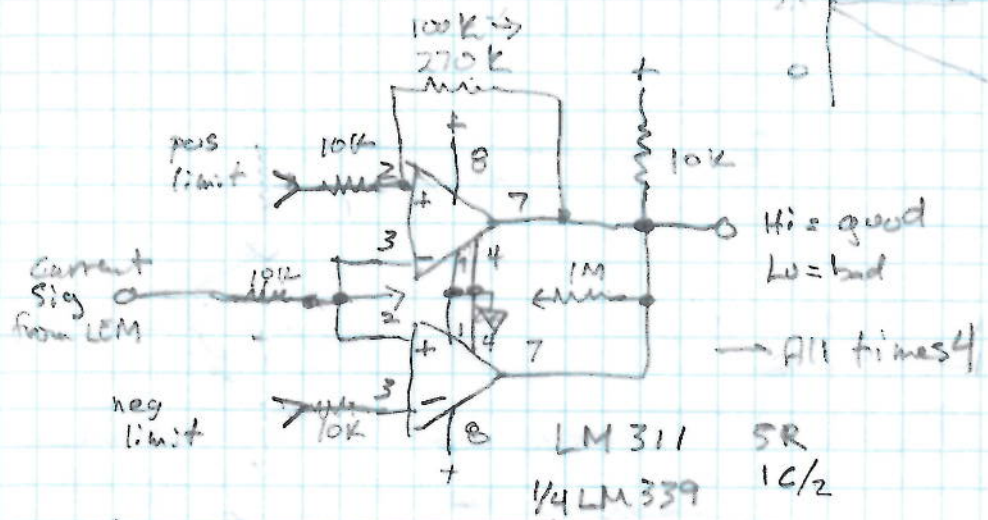
	uint16	
microlinc	offset = 2775	} To produce Amps
F-6-10	gain = 0.216	

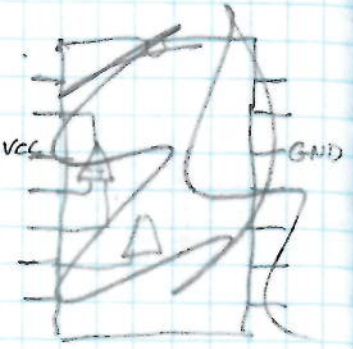
1000 RPM Test Data of 06/02

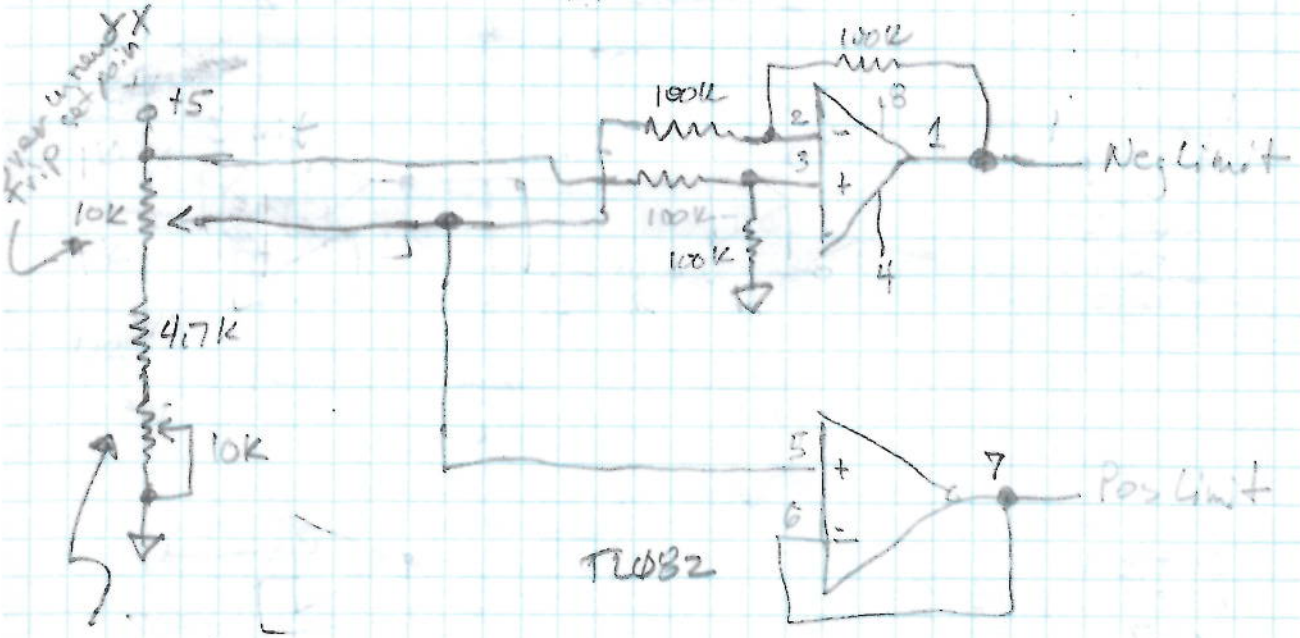
OK

$N_L = 2.5 - (P_L - 2.5)$
$= 2.5 - P_L + 2.5$
$= 5 - P_L$

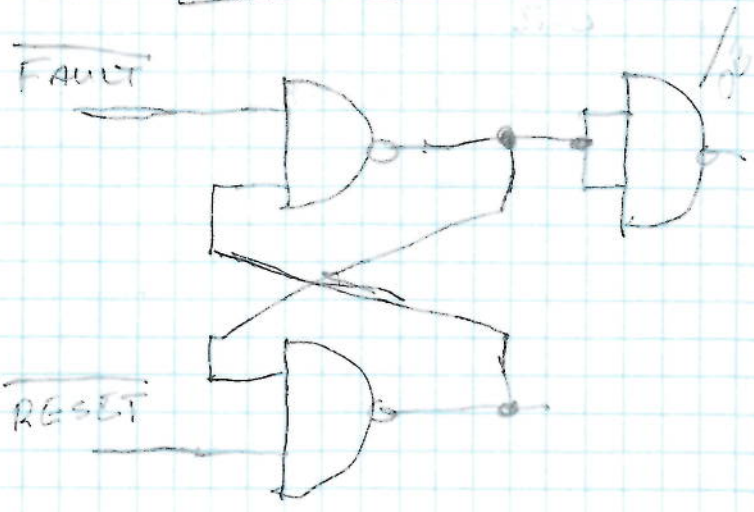


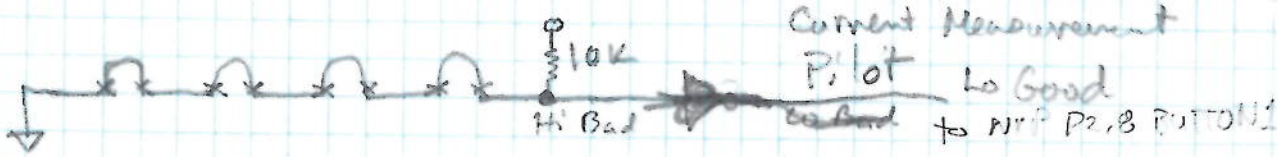




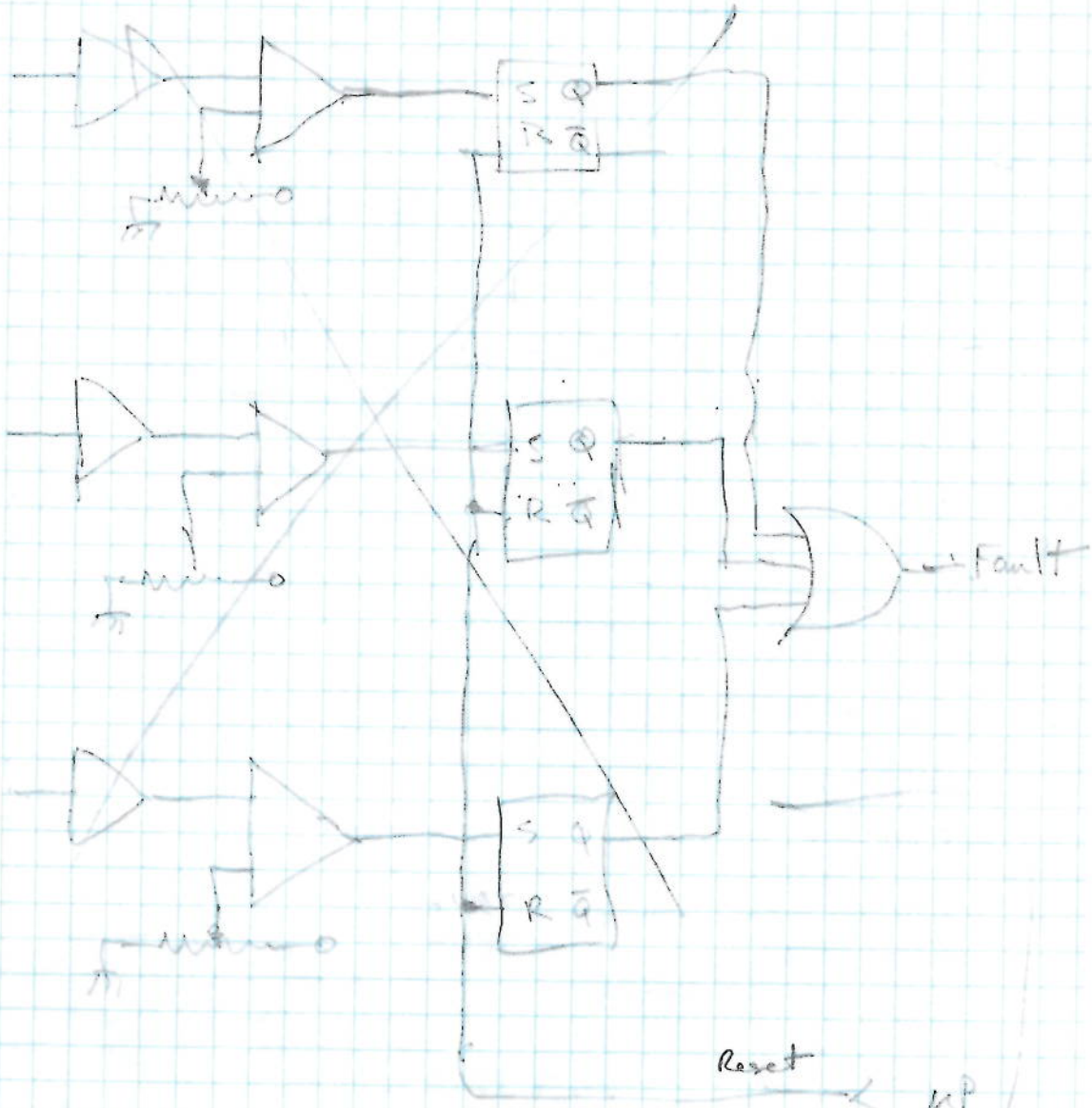


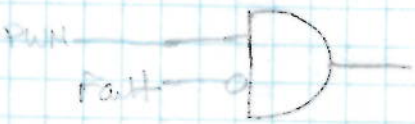
Adjust to equalize Neg + Pos Limit near 2.5V, with trip set point pot at minimum

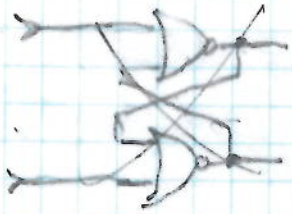


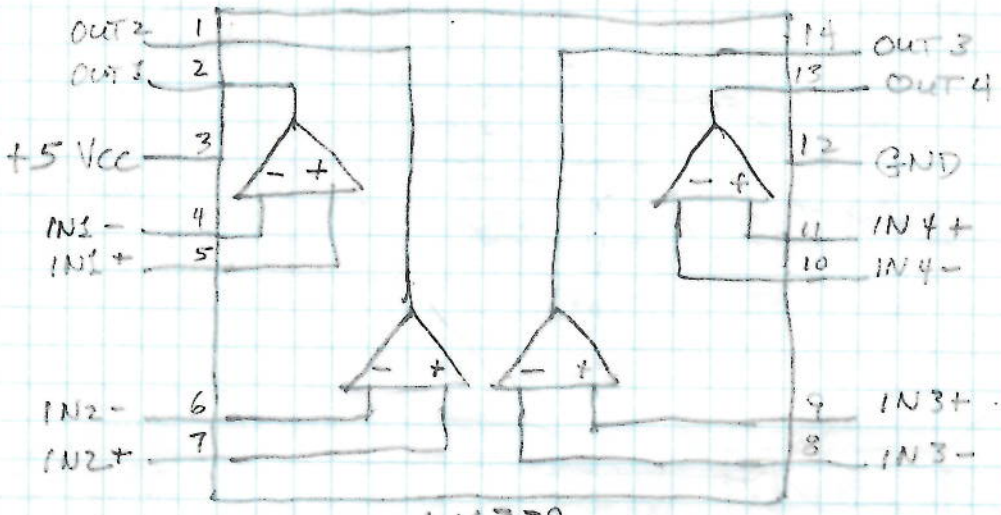


Over Current Protection

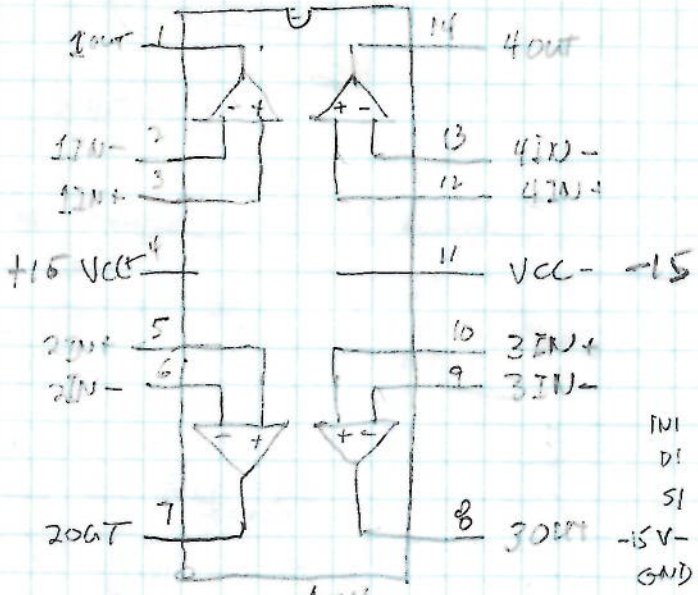








LM339



TL084

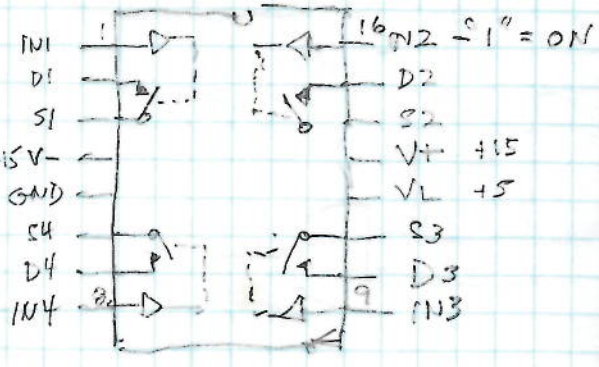
Sallen-Key Graph

2nd order Bessel

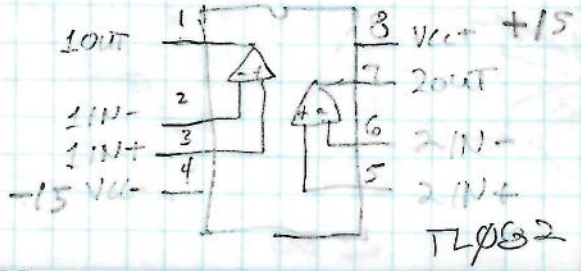
$a_i = 1.3617$ $b_i = 0.6180$

Butterworth

$a_i = 1.4142$ $b_i = 1.0000$



DG445



TL082

Parts Need

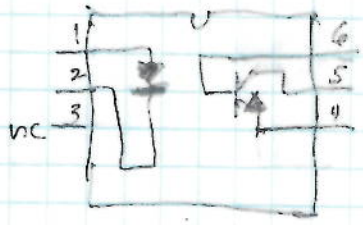
LM339 Comparator

4.7uF @ 35V decoupling caps

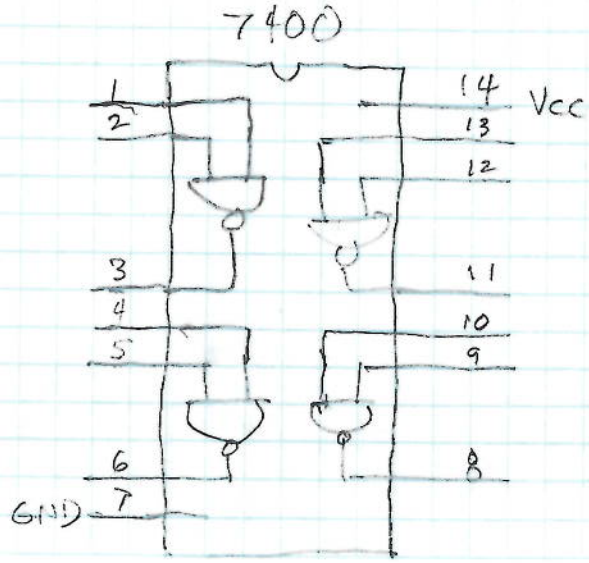
22uF@35V " "

7 pin latching connector, not like LEM

DG445 DJ-E3 Quad SPST switch 16 DIP



4N33



J1-23 -> Solenoid (+1)

J1-25 -> Precharge

J1-77,79 (GND) -> Coldplate thermistor

R1 = 270

R2 = 390 = 3.04 ✓

R2 = 440 = 3.27

C2		J1	Signal	Cable
m	→	83	CCD+	white
S	→	84	CCD-	blue
r	→	73	Accel Sens 1	orange
cc, P, EE	→	33,34	Sensor GND	Black/shield
q	→		+5V	Red
g	→	27	+5V	R/wht str. PC
A	→	21	0.1 −	Yellow (Green on Cable)
B	→	22	0.1 +	Blue/white (yellow on Pump Co

9/10 Doug to Hospital
Wed

8/31 - 9/1

(1) Found R-C filter added at LPC AI was C-R, not R-C. Took data anyway.

2.578 typ. File: with RC Backwards 3-1 volts.ods
"hash" ~ 10 counts p-p w/ 9 excursions (negative) down to 2000 to 2500 counts in 720 samples

RC filter: (2) Corrected filter to R-C 22K - 10,000 pF
took data

22×10^{3}
22×10^{-3}
22×10^{-12}
22×10^{-9} sec

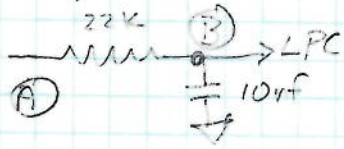
6 amps

File: Proper RC 3-1 volts.ods

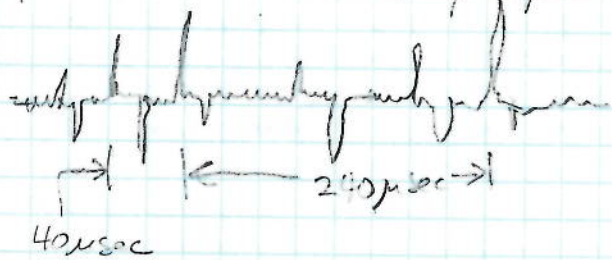
hash mostly 3 counts p-p (2.578 ± 1) w/ some excursions ± 20 counts

± 1.5A.

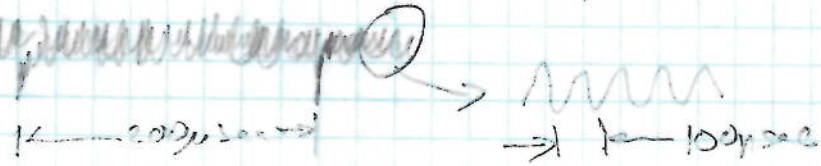
'Scope shows at (A) < 4 mV p-p hash (20 MHz bandwidth) with short bursts of negative 4 mV additional "noise" - ~ 2.3 msec long, 1 msec long, etc. Maybe about 100 μsec period of spikes in burst. Hash shows ~ 12 nsec rep. spikes



at (B) 15 mV p-p hash with very repetitive pattern



(3) Removed Capacitor
Took data - File: R only 3-1 volts.ods
Appearance similar to (1) 'scope (B) shows distinct negative spike solid @ 200 μsec periods



'scope (A) similar to (2) - Removed (A) from chip - noise bursts

(4) per (3) noise bursts apparently from CAN Bus. Added low inductance 3.3uF cap to CAN controller power bypass (and to LPC for good measure) Scope shows no more bursts but still isolated spikes, always negative, apparently 4mV but maybe much larger?

Scope at (1)

When "get snap" active, much noise shows on scope –

file: R only CAN Bypass 3-1 volts.ods

same as (3) (Suise 200KHz)

(5) Scope U8-6,7 50mV

(6) Separated copper Ground Bus from board ground in attempt to institute separate digital + analog grounds. It looks like most or maybe all analog circuits are grounded to Copper bus. No change in data.

file: R only Analog Ground 3-1 volts.ods

(7) Removed 3.3V power – much nicer noise spectrum ~1mV p-p hash w/ <4mV p-p transients

(8) wired LPC ground to same point as new analog ground wire

Data file:

noise seems rather better – maybe strict separation of grounds is way to go.

(9) Connected LEM – wired in heater

at NKP AI
- zero current – no obvious additional noise
- heater on – 118 mV p-p nice sine wave centered at 1.72 volts

after correcting data collection file:
Heater with revised data collection.ods

(10) on above pot (20 watts of light bulb

~ 8 mV p-p with noise

noise ~ 4 mV p-p bursts
w/ bursts @ ~ 4.8 usec
base noise ~ 1 mV p-p

Noise same w/o lamps on
Noise same w/o LEM plugged in
Noise same w/ LEM inputs shorted

(11) LEM – no current. (also no 'scope probe)
file: zero current LEM.ods

(12) Added 33uF + 0.1uF bypass caps to +5 and ±15 V supply to board
file: zero current after bypass.ods

Resolver Emulator

Ref input ~~sine~~ sine wave $K_r \sin(\omega t)$

sin output $= K \cdot K_r \sin\theta \sin(\omega t)$

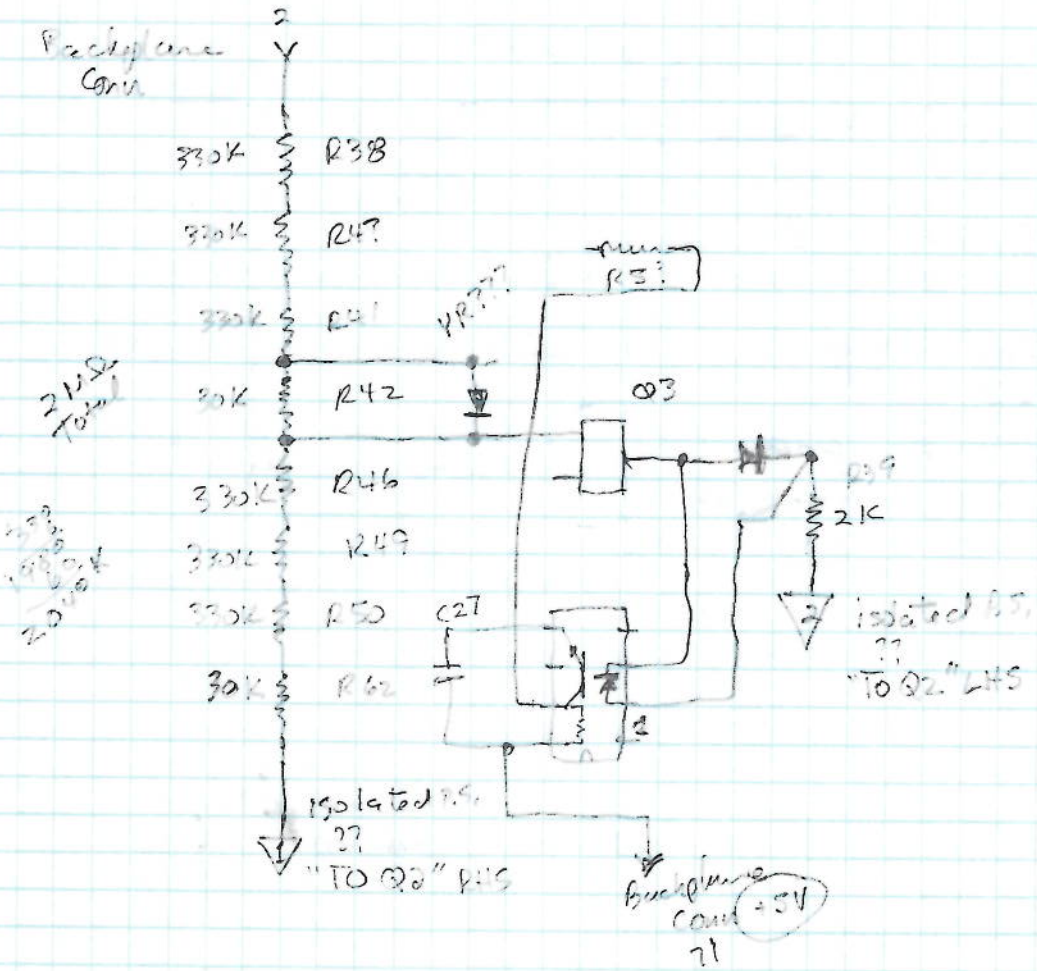
cos output $= K \cdot K_r \cos\theta \sin(\omega t)$

where θ is shaft position $\omega = 2\pi f$ = ref. frequency

if shaft is rotating at x rpm $= \frac{x}{60}$ rps

or $\omega_x = 2\pi \frac{x}{60}$

HV Circuit on Driver Board



MCP 3208 Cmd's

cmd4 is working but probably wrong

cmd4 was intended to be chan Ø single ended

when chan 1 is connected to bus current the zero current state reads 809 counts 2V - 1.66 = .44v. Disconn chan Ø gives 3336, Disconn chan 1 gives 1930 (old val)

using cmd 5 reads Ø

cmd 8 - should be single ended chan Ø, is dif 1, 0

cmd 4 should be diff chan 4, 5, is dif 0, 1

5.2ip 9.2ip

0 - 0 0000|0000 dif 0, 1 0
0000 1000 dif 1, 0 1
0001
0100 0...
4 0

0 - 4092 pegged
1 - 2225, slightly reacts to both 0, 1
4 0, 1 1
5 - ?
8 - 10 1
9 - ?
x 40 - like Ø
x 48 - ?

5 5
0101 0101
A A
1010 1010

x40 - Dif
x80 - bit rev
x20 - ?
x10 - ?
x08
x04

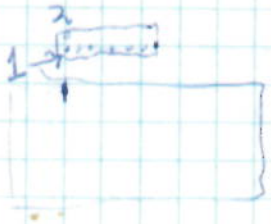
11000

start bit needs to be 1 bit

J1 - C2 Connections

Group

C2	J1		C2	J1
✓ q	27	5V	E, C, G, H, DD, CC, c, EE	1-20
- ✓ p	17	GND	BB, p, J, K, L, M, N	
- ✓ r	73	Accel		
- ✓ m	83	Can +	q, AA, g, A, B, t,	21-40
- ✓ s	84	Can -	CC, c, BB, p, X, Z, f, K, N	41-60
✓ g	28	5V		
AA	24	pump pressure (+)	N, R, K, c, x, y, z, n, FF	61-80
BB	18	pump press (-)	d, c, p, BB, HH, EE, CC, y, V, c, W	
B	22	oil pump -		
A	21	oil pump + 42	N, R, h, f, a, z, y, c	81-100
	34	fan - (GND), 19	p, BB, EE, c, CC, c	
	63	fan +		



(test)

J7-1 Phase A filter out
J7-5 Phase A A-D in
J7-7 Phase C filter out
J7-9 FAN
J7-11 Ored Fault
J7-13 Latched Fault

J7-2 +5V
J7-6 -15V

Smooth ORPM tuning 11/13/14

try		Result
P (Q&D) from .8 to .2	—	Less energy, B = 5Hz 15ft-lbs
Poles from 4 -> 2	—	Faster more energetic, B = 5Hz
Poles 2 -> 4 Magtable @ 0 RPM 500 -> 100	—	3ft-lbs B = 20Hz
Magtable @ 0 500 -> 750	—	15ft-lbs, B = 2-3Hz
Magtab @ 0 150-1000	—	15 ft-lbs, B = .5-1 broke string...
Magtab @ 0 1000 -> 1250 Filter 2 -> 25	—	18 ft-lbs B = 0-.5 very strong but also sudden torque...
remove positive sense (tot)		B = 1
reduce Tr 0.04 -> .02..		B = 5
reduce Tr .02... -> .01..		"
Poles 4 -> 2 Tr .01 -> .005		No torque all Amps
Tr .005 -> .3		high Freq B 30+? Low torque
Tr .3 -> .03183, mod slip Alpha Also replaced R6 10k -> 1k	—>	maxed scale some pulse good speed
Adjust Current limit to .75 -> 1.5 ✓		Limit is ok but transient spikes affect CANBUS!

Te measurement – Bob's motor

Run 1 ln ΔV = 2.93
Δt = 0.04
TR = 117 msec

Run 2 ΔV = 15 V

Tr = 108

Run 3 Tr = 108

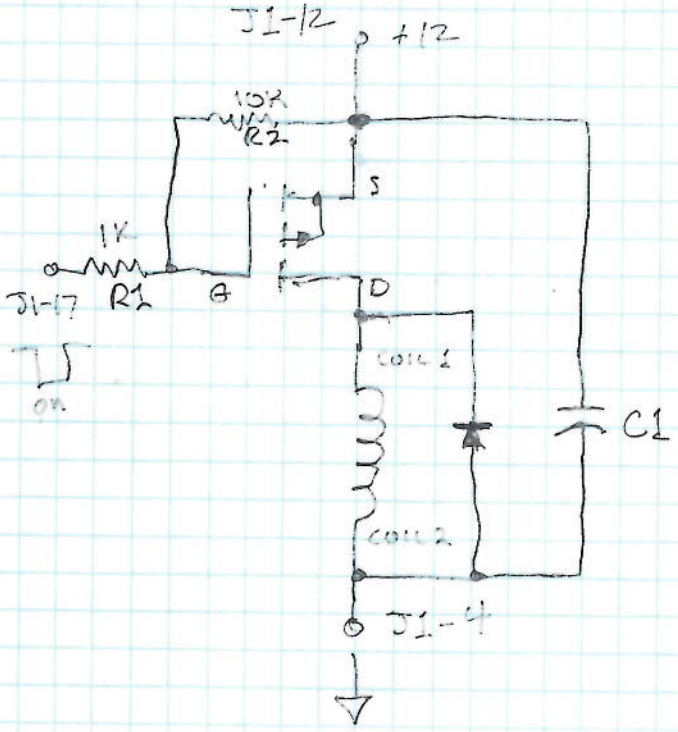
→ AMP EVC500-ALADIN

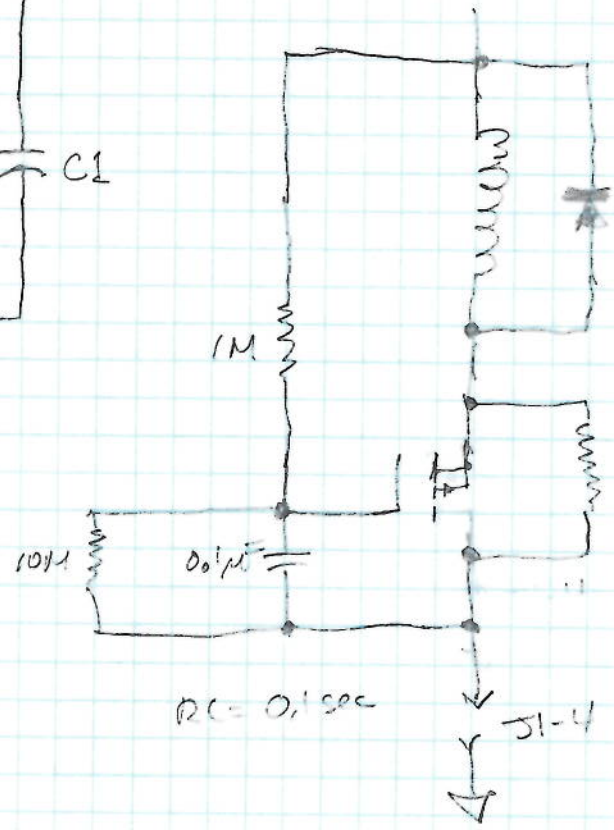
aka

Tyco Electronics

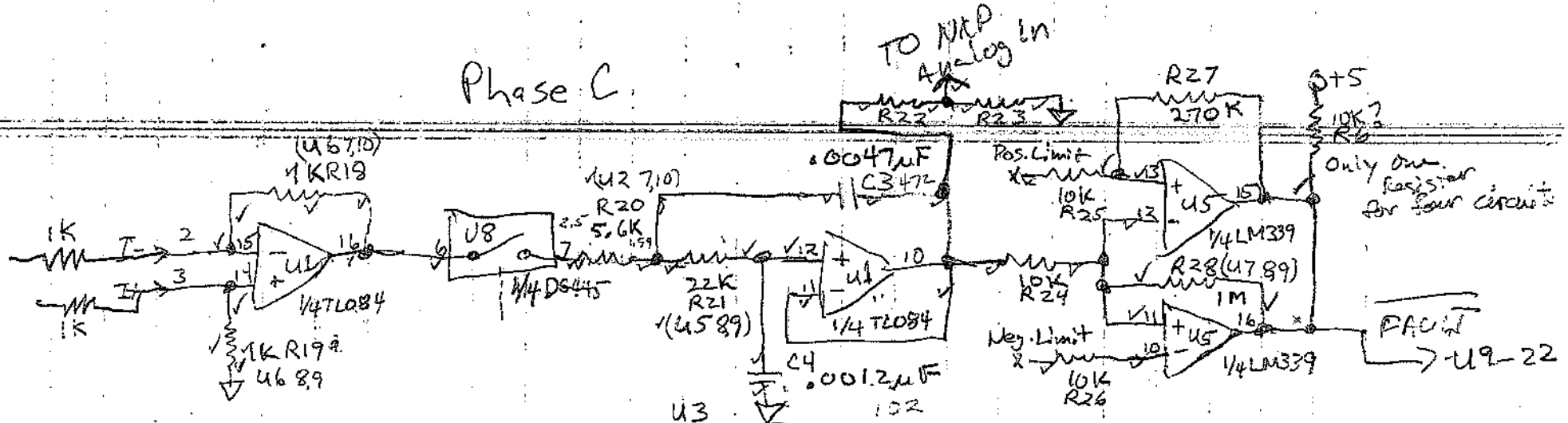
2098372-1

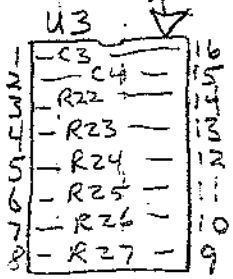
12-24 VDC coil

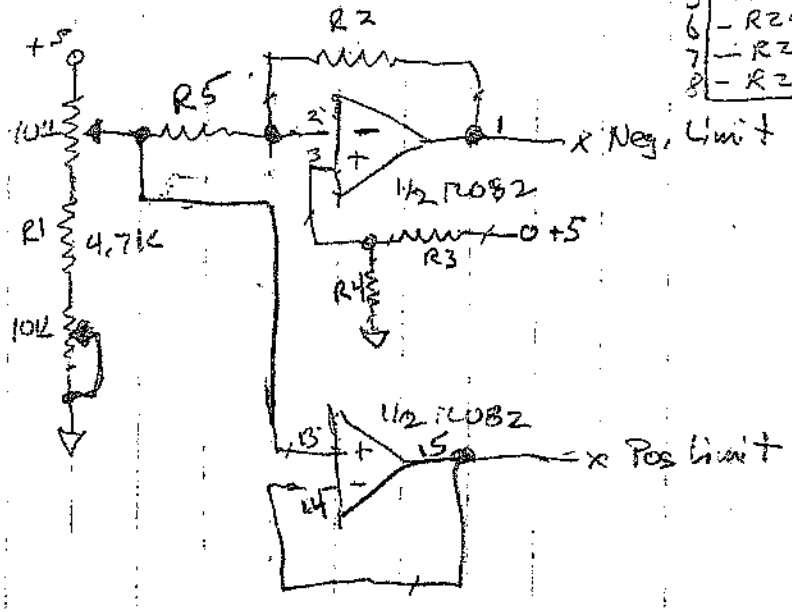




Phase C







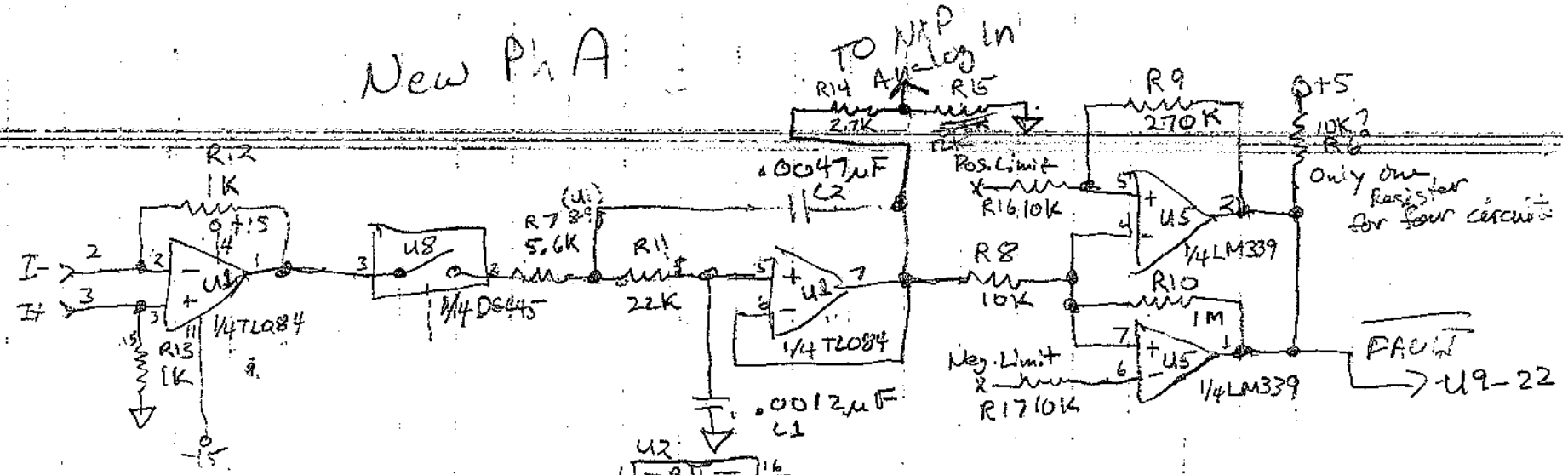
For 1 Channel 1/2 TL084
1/2 LM339
1/4 DG445
10/8 Discrete

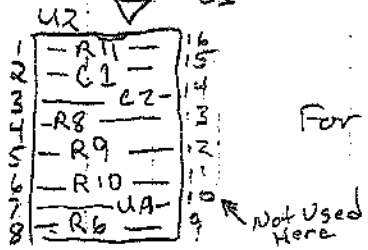
For 4 Channels 2 TL084
2 LM339
1 DG445
40/8 Discrete = 5
= 10 sockets

4/8 discrete = 0.5 sockets
1 TL082 = 0.5 sockets
} 1 socket

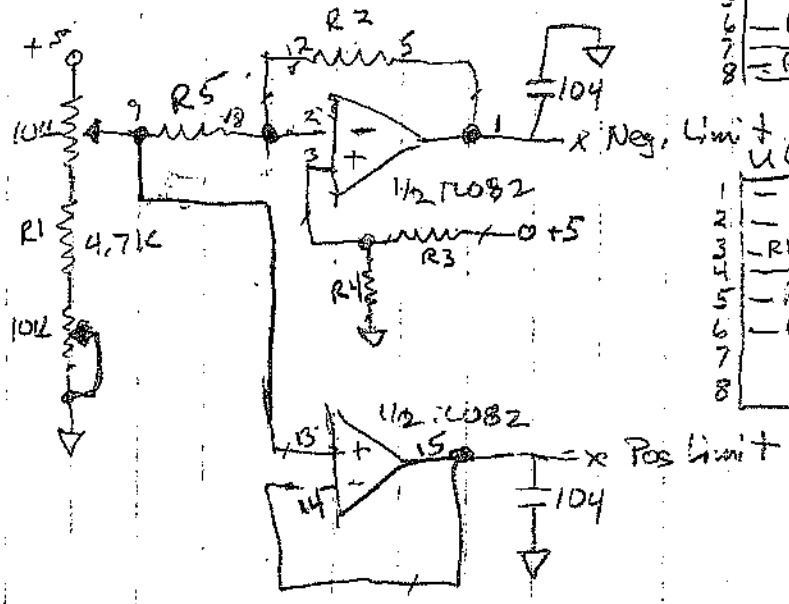
Grand Total
6 + 11 sockets

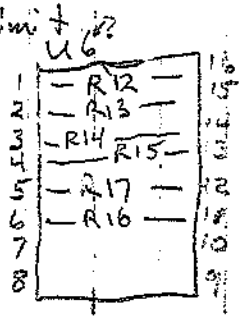
New PhA





For 1 Channel
1/2 TL084
1/2 LM339
1/4 DG445
10/8 Discrete

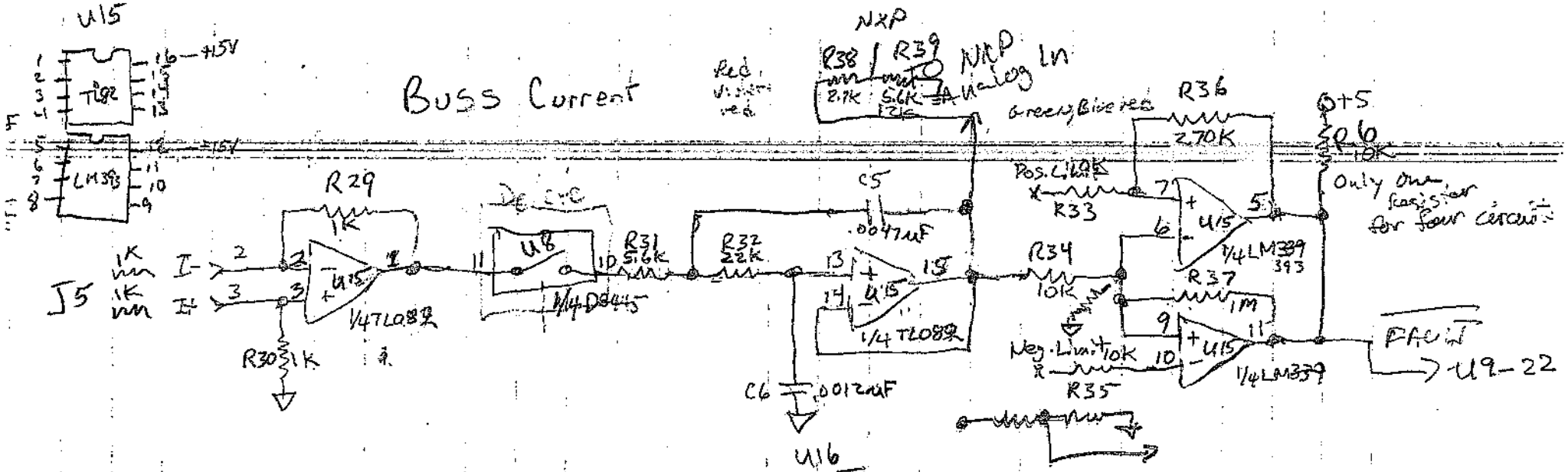




For 4 Channels
2 TL084
2 LM339
1 DG445
40/8 Discrete = 5
= 10 sockets

4/8 discrete = 0.5 sockets
1/1 TL082 = 0.5 sockets
} 1 socket

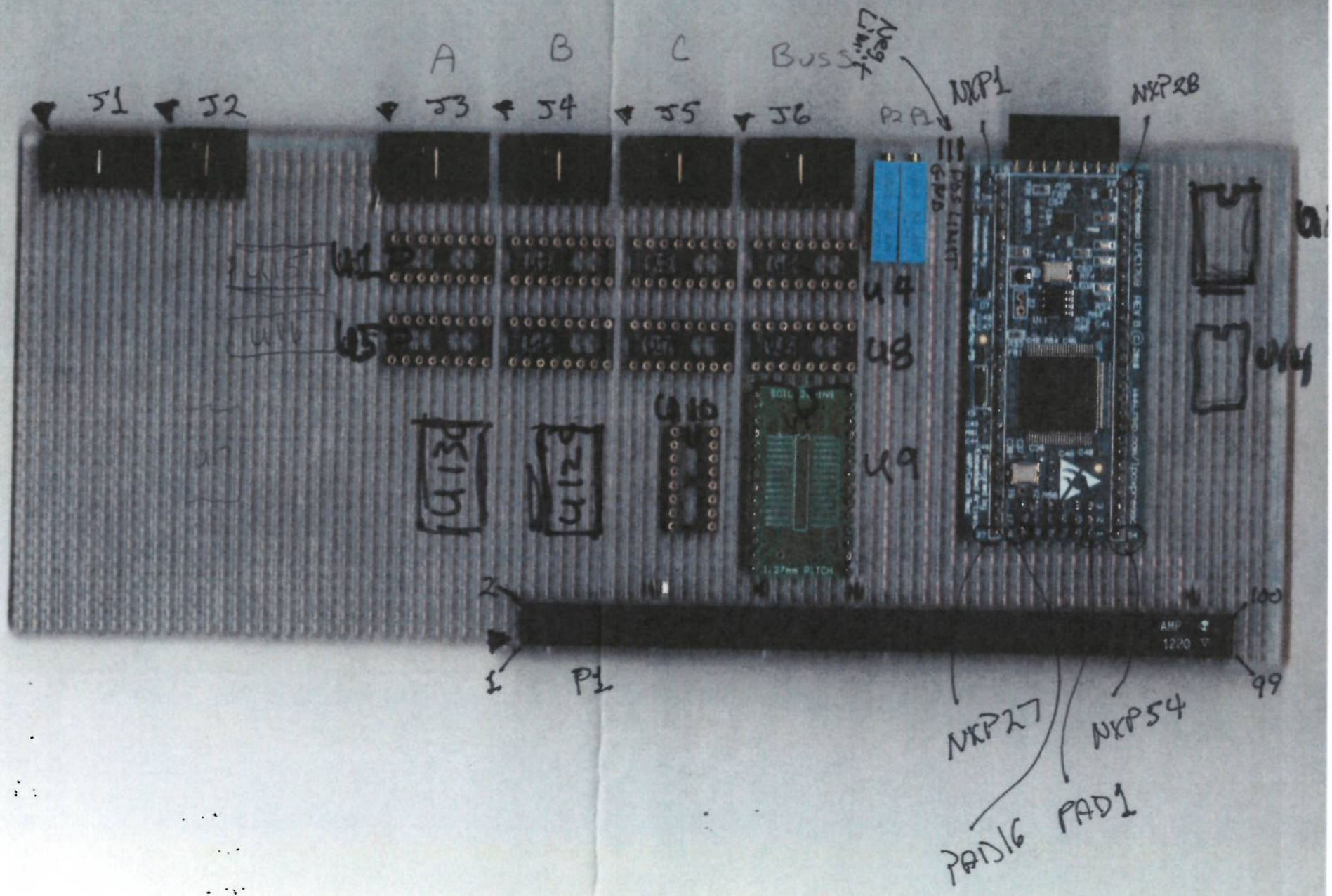
Grand Total
9 + 11 sockets



4/8 discrete = 0.5 sockets
1.1 TL082 = 0.5 sockets
} 1 socket

Grand Total

9 + 11 sockets


ASSIGNED 1,5,3,7,8,6
A
B
C
BUSS
J1
J2
J3
J4
J5
J6
P2 P1
NXP1
NXP28
U1
U5
U4
U8
U10
U9
U14
U12
U12
2
1
P1
100
99
NXP27
NXP54
PAD16
PAD1

Decouple U9, 10, 12, 13

NXP Power

GND -> J6-1, J6-5 ✓ decouple

+5 ✓ -> J6-2

CAN

U11-15 (CanH) ✓ -> ✓ J1-83 U11-2 ✓ decouple

U11-14 (CanL) ✓ -> ✓ J1-84 U11-3 ✓

Current limit reference

U4-4 ✓ -> ✓ -15V

U4-16 ✓ -> ✓ +15V

U4-1 ✓ -> ✓ U4-5 -> Neg limit

U4-12 ✓ -> ✓ U4-2

U4-3 ✓ -> ✓ U4-6

U4-11 ✓ -> ✓ +5V

U4-6 ✓ -> ✓ U4-7

U4-10 ✓ -> ✓ GND

U4-2 ✓ -> ✓ U4-13

U4-15 ✓ -> ✓ U4-14 -> Pos limit

U4-2 ✓ -> ✓ R13

U4-9 ✓ -> ✓ R5 Pot1 (center)

Pot1 (top) ✓ -> ✓ +5V

Pot1 (bot) ✓ -> ✓ R1 ~~Need 1 more Res location~~

R1 ✓ -> Pot2 (top)

Pot2 (center) ✓ -> ✓ Pot2 (bot)

Pot2 (bot) ✓ -> ✓ GND

U4-8 ✓ -> ✓ U4-2

1		16
2		15
3	U4	14
4		13
5	R2	12
6	R3	11
7	R4	10
8	R5	9

Phase A current J3

TL084
U1

16	J3-2 ✓->✓	U1-2	~~U1-2 -> U3-1~~	U1-4 ✓->✓ +15v
15				
14	J3-3 ✓->✓	U1-3	U3-16 -> U1-2	U1-13 ✓->✓ -15v
13				
12	U1-1 ✓->✓	U8-3	U1-3 -> U3-2	U8-4 ✓->✓ -15v
11				
10	U8-2 ✓->✓	U1-8	~~U3-15 -> GND~~	U8-5 ✓->✓ GND
3-R7-9 5.6K	U1-9 ✓->✓	U2-1	~~U6-3 -> U2-14~~	U8-12 ✓->✓ +5v
	U2-16 ✓->✓	U1-5	~~U6-14 -> U6-13~~	U8-13 ✓->✓ +15v
DG445 U8	U1-6 ✓->✓	U1-7	~~U6-4 -> GND~~	U5-3 ✓->✓ +5v
16				
15	U1-9 (U2-1) ✓->✓	U2-3	~~U6-14 -> J6-22~~	U5-14 ✓->✓ GND
14				
13	U1-16 ✓->✓	U2-2		
12				
11	U2-15 ✓->✓	GND		J3-4 ✓->✓ GND
10				
9	U1-7 ✓->✓	U2-4	U6-5 ✓->✓	U5-6 J3-5 ✓->✓ +15v
LM339 U5	U2-13 ✓->✓	U5-4	U6-12 ✓->✓	U4-1 U6-4 ✓->✓ J6-22 AI6
16				
15	U2-13 ✓->✓	U5-7	U2-9 ✓->✓	+5v
14				
13	U5-5 ✓->✓	U2-5	U6-6 ✓->✓	U5-5
12				
11	U5-2 ✓->✓	U2-12	U6-11 ✓->✓	U4-15
10				
9	U5-7 ✓->✓	U2-6		
	U2-11 ✓->✓	U5-1		
	U5-1 (U2-12) ✓->✓	U5-2		
	U5-2 ✓->✓	U2-8		
	U2-9 ✓->✓	+5v		
	U6-1 ✓->✓	U1-2		
	U6-16 ✓->✓	U1-1		
	U6-2 ✓->✓	U1-3		
	U6-15 ✓->✓	GND		

Head Unit Cable

Red +12v

Grn GND

Blue CANL

Yellow CANH

U6-14 ✓->✓ U2-14

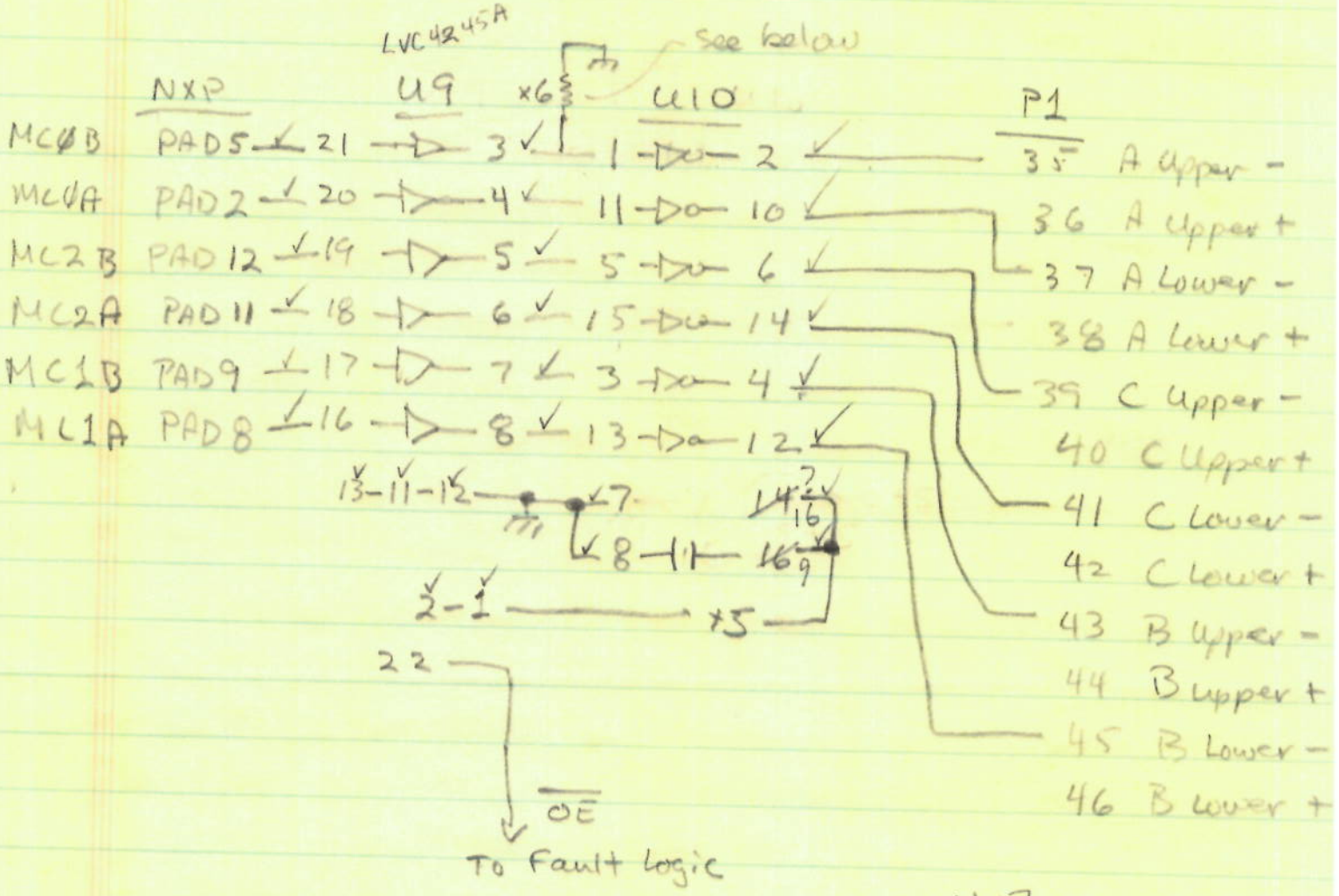
U6-3 ✓->✓ U6-4

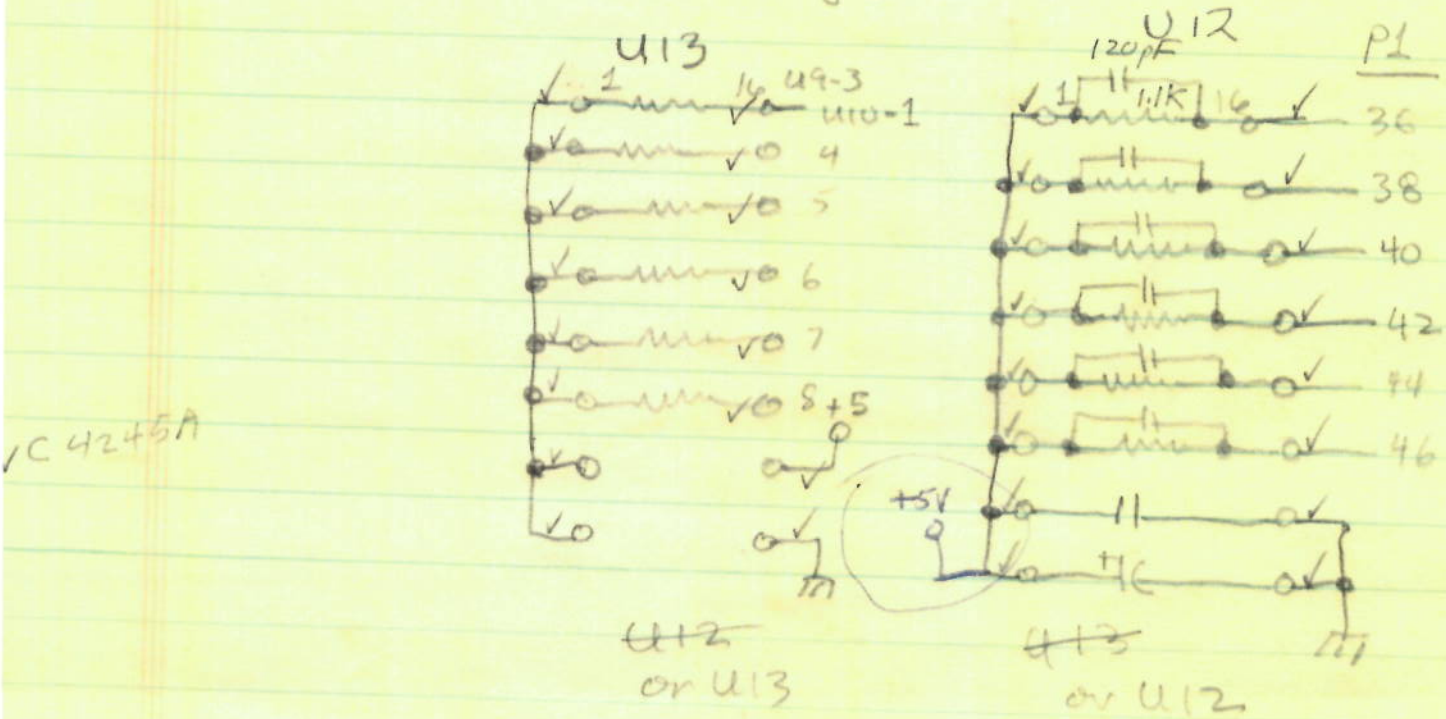
U6-13 ✓->✓ GND

U6-3 -> MXP J6

U2-14 ✓->✓ U2-7

IGBT DRIVE


LVC 4245A
U9
U10
NXP
x6
See below
MCØB PAD5 21 3 1 2
MCØA PAD2 20 4 11 10
MC2B PAD12 19 5 5 6
MC2A PAD11 18 6 15 14
MC1B PAD9 17 7 3 4
MC1A PAD8 16 8 13 12
13-11-12
7
8
14 16
2-1
x5
22
OE
To Fault logic
P1
35 A Upper -
36 A Upper +
37 A Lower -
38 A Lower +
39 C Upper -
40 C Upper +
41 C Lower -
42 C Lower +
43 B Upper -
44 B Upper +
45 B Lower -
46 B Lower +


U13
U9-3
U10-1
4
5
6
7
8 +5
IC 4245A
U12
120pF
1.1K
P1
36
38
40
42
44
46
+5V
U12
or U13
U13
or U12

Buss Current

✓ J5-2 ✓ → ✓ U15-2
✓ J5-3 ✓ → ✓ U15-3
✓ U15-3 ✓ → ✓ U16-2
✓ U15-2 ✓ → ✓ U16-1
✓ U16-16 ✓ → ✓ U15-1
✓ U16-15 ✓ → ✓ GND
✓ U15-1 ✓ → ✓ U16-3
✓ U16-14 ✓ → ✓ U16-6
✓ U16-14 ✓ → ✓ U16-4
✓ U16-11 ✓ → ✓ U16-5
✓ U16-12 ✓ → ✓ GND
should be U16-14 ✓ U16-12 ✓ → ✓ U15-13
✓ U15-14 ✓ → ✓ U15-15
✓ U15-14 ✓ → ✓ U16-13
✓ U16-13 ✓ → ✓ U17-4
✓ U17-13 ✓ → ✓ U17-12
✓ U17-5 ✓ → ✓ GND
✓ U17-12 ✓ → ✓ NXP(J6-17)
✓ U15-15 (U17-4) ✓ → ✓ U16-8
✓ U16-9 ✓ → ✓ U15-6 ✓, 9 ✓
✓ U4-1 ✓ → ✓ U17 1
✓ U4-15 ✓ → ✓ U16-7
✓ U16-10 ✓ → ✓ U15-7
✓ U17-16 ✓ → ✓ U15-10
✓ U15-7 ✓ → ✓ U17-2
✓ U17-15 ✓ → ✓ U15-5

✓ U15-9 ✓ → ✓ U17-3
✓ U17-14 ✓ → ✓ U15-11
✓ U15-5 (U17-15) ✓ → ✓ U15-11 (U17-14)
✓ U15-5 all ✓ → ✓ U2-8 (U5-15)

✓ U15- ,16 ✓ → ✓ +15V
✓ U15- ✓, 8 → GND
✓ J5 ✓ 4, 6 ✓ → GND
✓ J5 - ✓5 ✓ → ✓ +15V
✓ U15-4 ✓ → ✓ -15V
✓ U15-12 ✓ → ✓ +5V

36

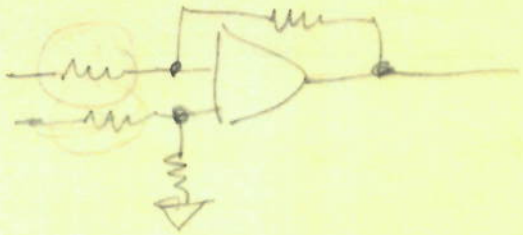
Phase C current

J4-2 ✓→✓ U1-15
J4-3 ✓→✓ U1-14
U1-16 ✓→✓ U8-6
U1-15 ✓→✓ U6-7
U1-16 ✓→✓ U6-10
U8-7 ✓→✓ U2-7
U2-10 ✓→✓ U5-8
U6-8 ✓→✓ U1-14
U6-9 ✓→✓ GND
U5-9 ✓→✓ U1-12 —
U1-10 ✓→✓ U1-11
U2-10 ✓→✓ U3-1
U3-16 ✓→✓ U1-10
U1-10 ✓→✓ U3-3
U3-14 ✓→✓ U3-13
U3-4 ✓→✓ GND
U3-13 ✓→✓ NXP (J6-21) AI7
U3-2 ✓→✓ U5-9
U3-15 ✓→✓ GND
Should be U4-15 * U4-1 ✓→✓ U3-6 —
U3-11 ✓→✓ U5-13
should be U4-1 * U4-15 ✓→✓ U3-7
U3-10 ✓→✓ U5-10
U1-10 ✓→✓ U3-5
U3-12 ✓→✓ U5-12 → 11
U5 11 ✓→✓ U7-8
U7-9 ✓→✓ U5-16

J4

U5-15 ✓→✓ U5-16
U3-8 ✓→✓ U5-13 (U3-11)
U3-9 ✓→✓ U5-15 (U2-8)
U5-15 ✓→✓ U2-8

J4-4 ✓→✓ GND
J4-5 ✓→✓ +15V
J4-6 ✓→✓ GND



Code

~~clear msgs~~, ~~jog up/down~~, ~~test snapshot~~, ~~new temp table~~

mk II

populate PA limit + decouple

~~trace + resistor bridge temp sensor~~

~~mk II left side board support~~

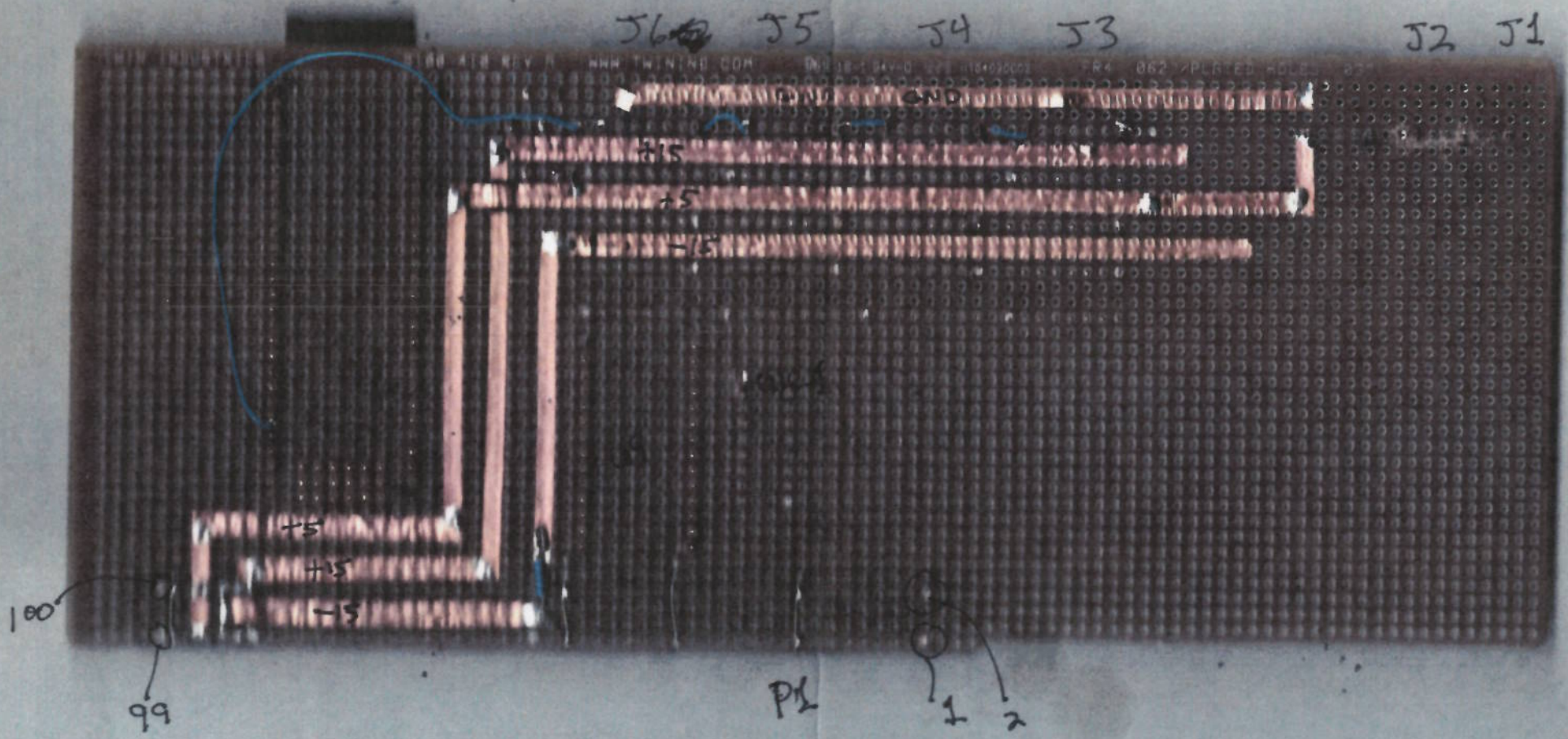
DegF	Counts
180	482
165	584
150	745
111	1385
82	2108
75	2191
38	2901
25	3079

Punch for Phase A limit

1. U8 - 2+3 on wrong pins
2. R6-R7 label + re-wire

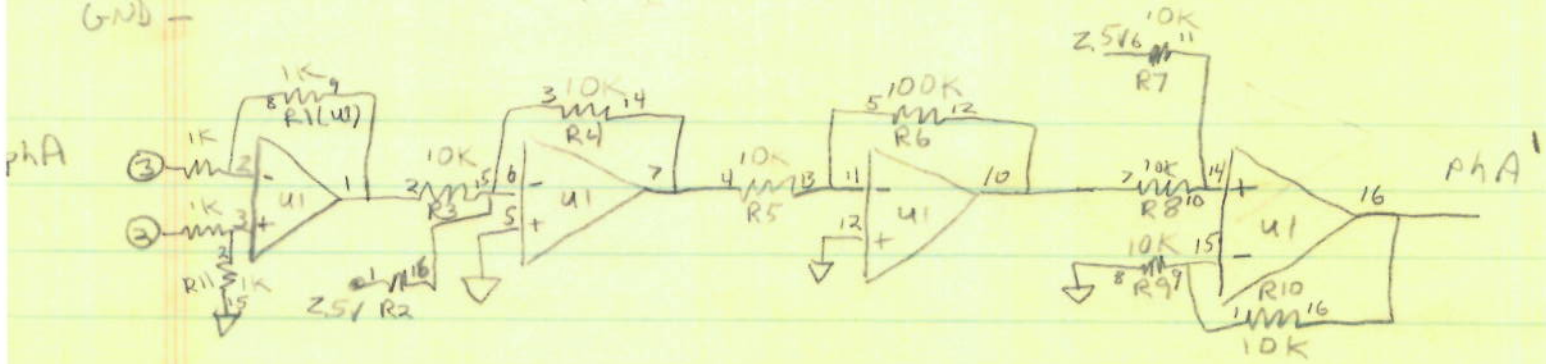
To Do

1. ~~decouple HC04 (U10) + level cvt (U9)~~ ✓
2. ~~Solder lvl cvt~~ ✓
3. ~~sw imp of fault/reset~~ ✓
4. ~~latch circuit design + locate~~ ✓
5. ~~SW I's to Head unit~~ ✓
6. ~~Latch wire + test fault/reset~~ ✓
7. ~~Head cable shell~~ ✓
8. ~~Populate U12-U13~~ ✓
9. ~~switch AC polarity~~ ✓


J6
J5
J4
J3
J2
J1
+5
+5
+5
+5
+5
+5
100
99
P1
1
2

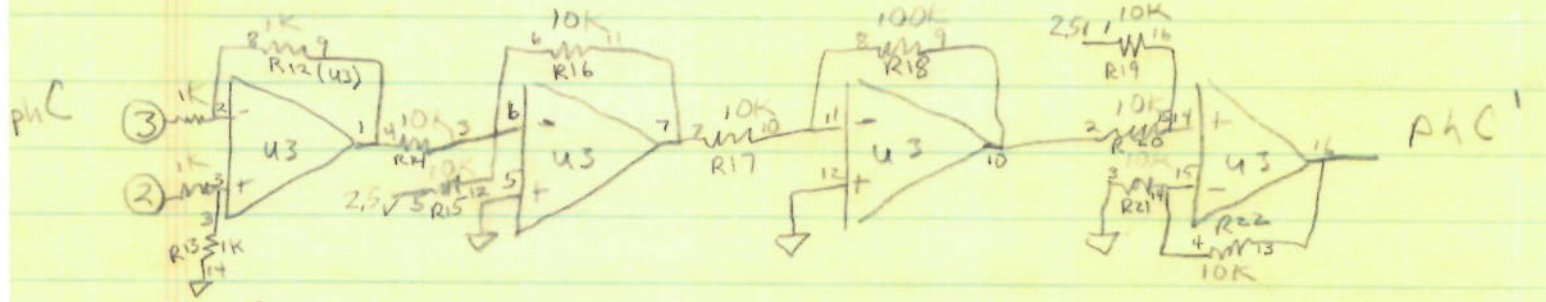
PRE-AMP

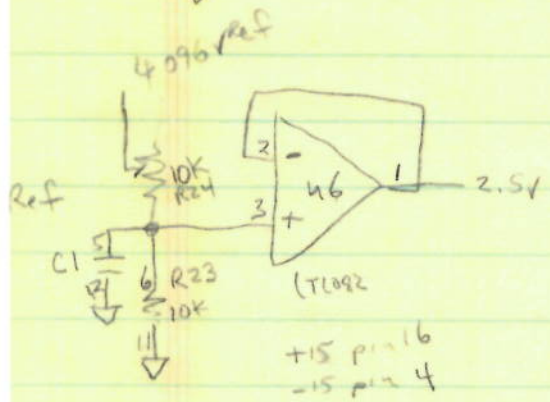
+15v —
-15v —
GND —



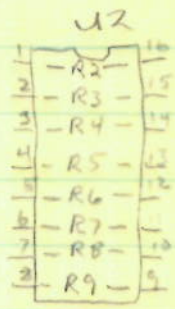
+15 pin 4
-15 pin 13

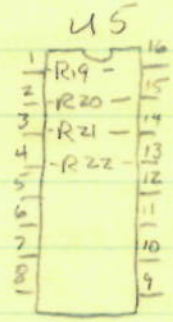
62500 - 64500

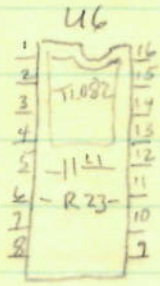




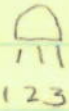
+15 pin 16
-15 pin 4



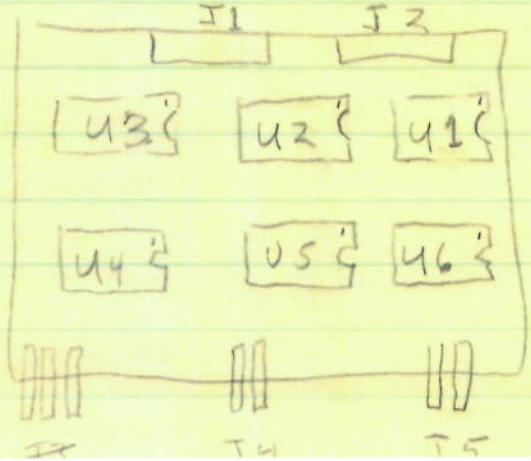


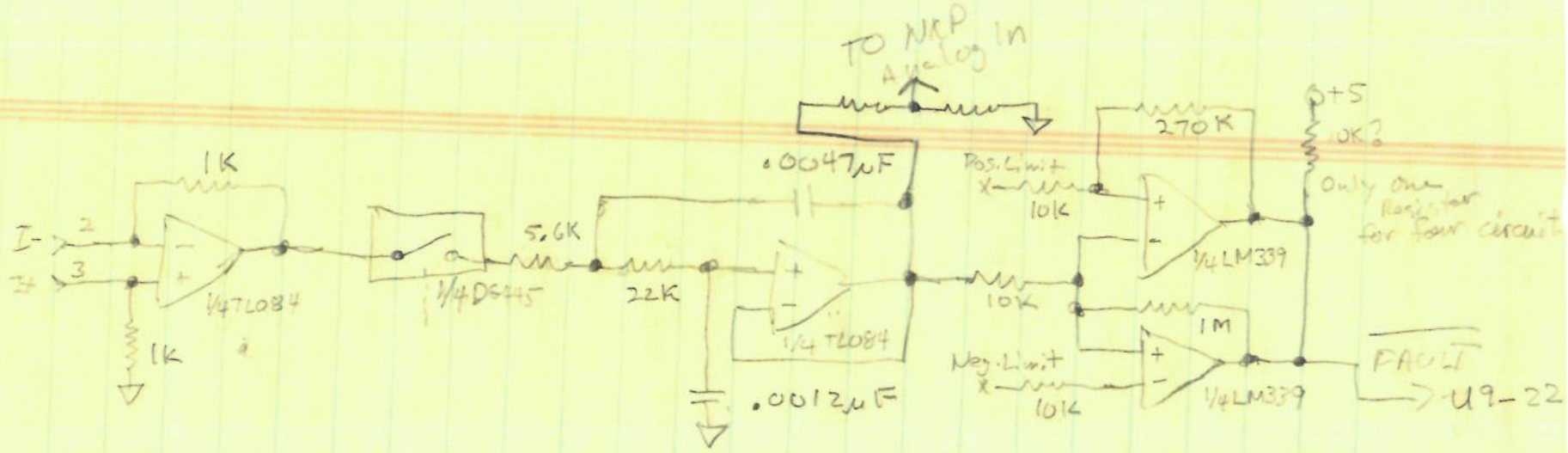


MCP1541



123





Pre charge / Solenoid / Thermister

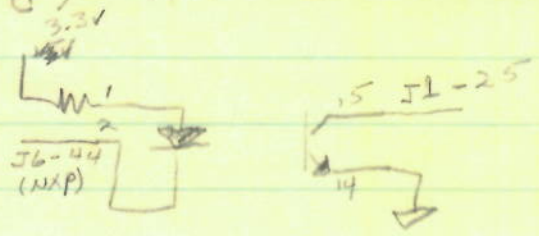
Pre

- U14-1 ✓→✓ U14-4
- U14-13 ✓→✓ +3.3V
- U14-2 ✓→✓ J6-44
- U14-14 ✓→✓ GND
- U14-15 ✓→✓ J1-25

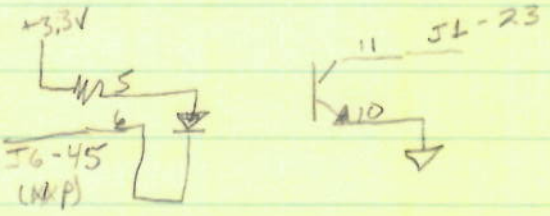
Sol

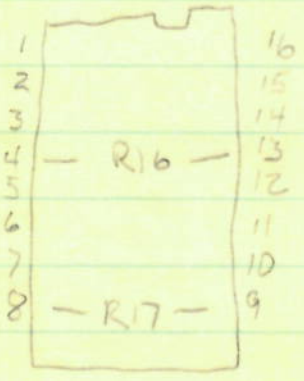
- U14-5 ✓→✓ U14-8
- U14-9 ✓→✓ +3.3V
- U14-6 ✓→✓ J6-45
- U14-10 ✓→✓ GND
- U14-11 ✓→✓ J1-23

Pre



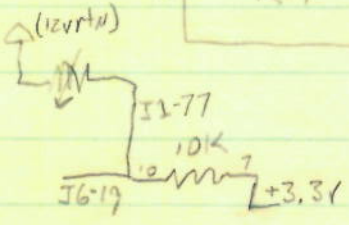
Sol





thermistor

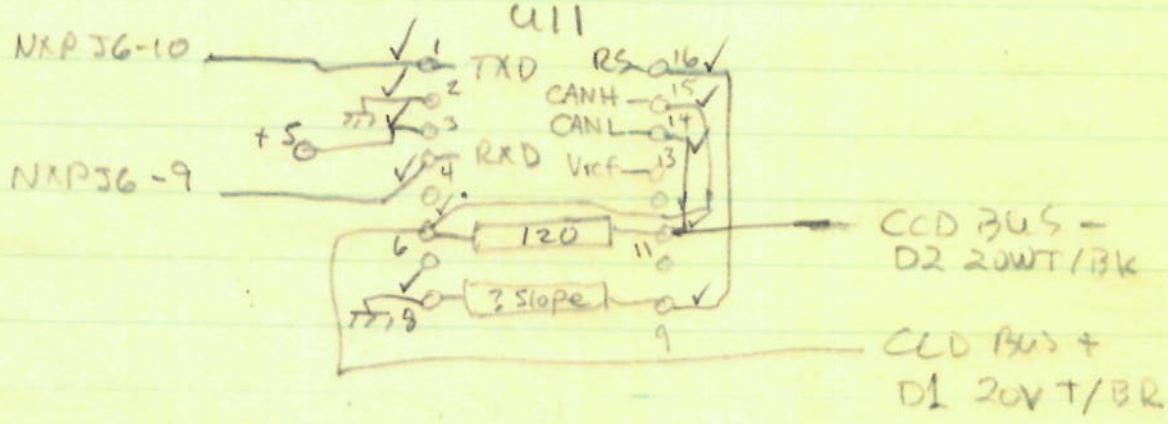
- U11-7 ✓→✓ +3.3V
- U11-10 ✓→✓ J6-19
- J1-77 ✓→✓ U11-10



Resolver

Mark IV Backplane Connector = #1

To Resolver					Pico Board
Ref+	P1-1	←	J1-1 ✓	←	J3-1
Ref-	P1-2	←	J1-2 ✓	←	J3-2
Cos+	P1-3	→	J1-3 ✓	→	J1-4
Cos-	P1-4	→	J1-4 ✓	→	J1-5
Sin+	P1-5	→	J1-5 ✓	→	J1-1
Sin-	P1-6	→	J1-6 ✓	→	J1-2
Gnd	P1-8	↔	J1-7 ✓	↔	J1-3

	NXP	J2			
Ph A (MCI0)	PAD3	← J2-1	← P1-1	A+	✓
Ph B (MCI1)	PAD6	← J2-2	← P1-3	B+	✓
IDX (MCI2)	PAD7	← J2-3	← P1-5	Z+	✓
	Bus Bar	- J2-5	- P1-9	+5V	✓
	Gnd Plane	- J2-4	- P1-10	GND	✓

CAN Bus