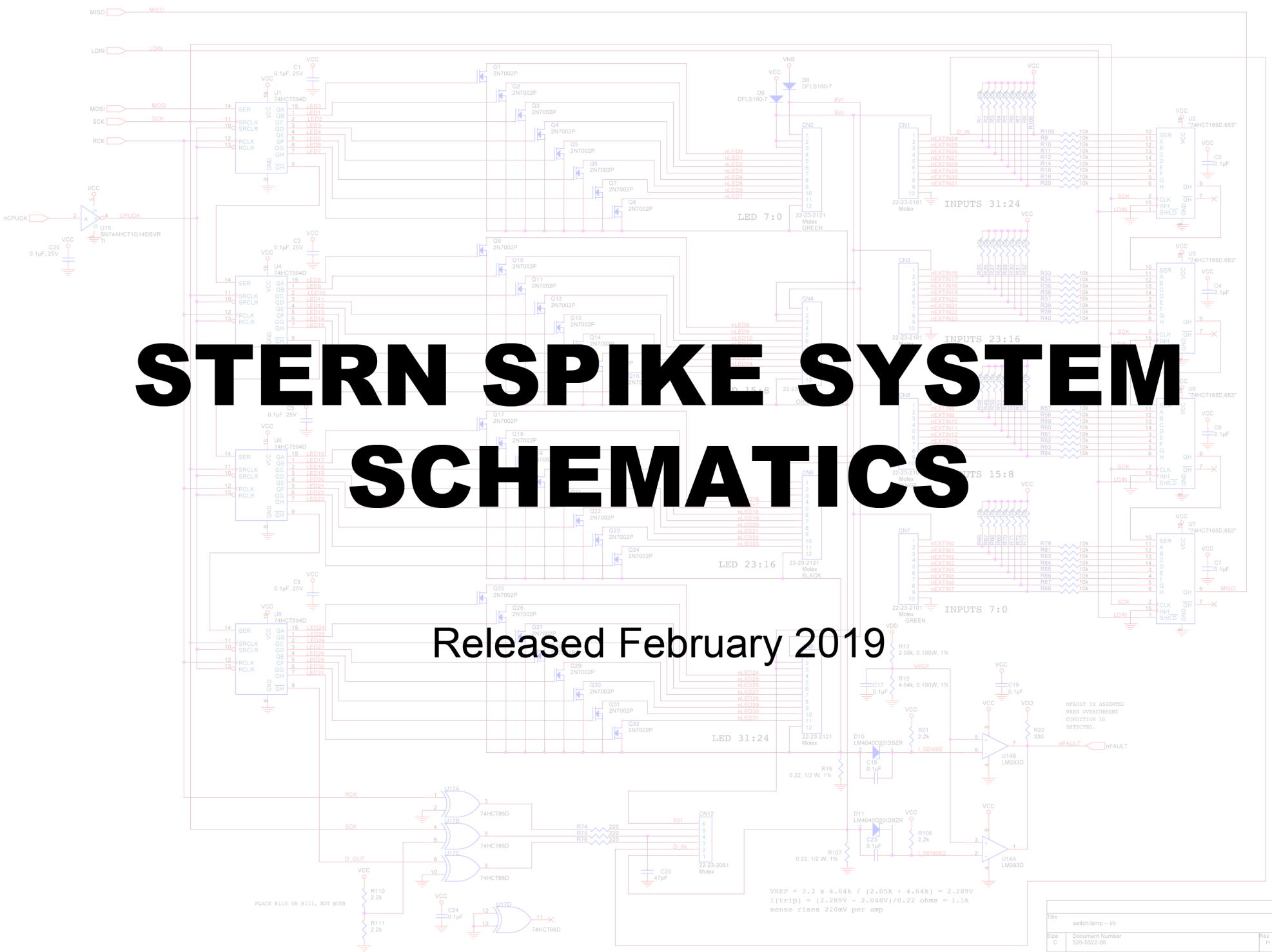
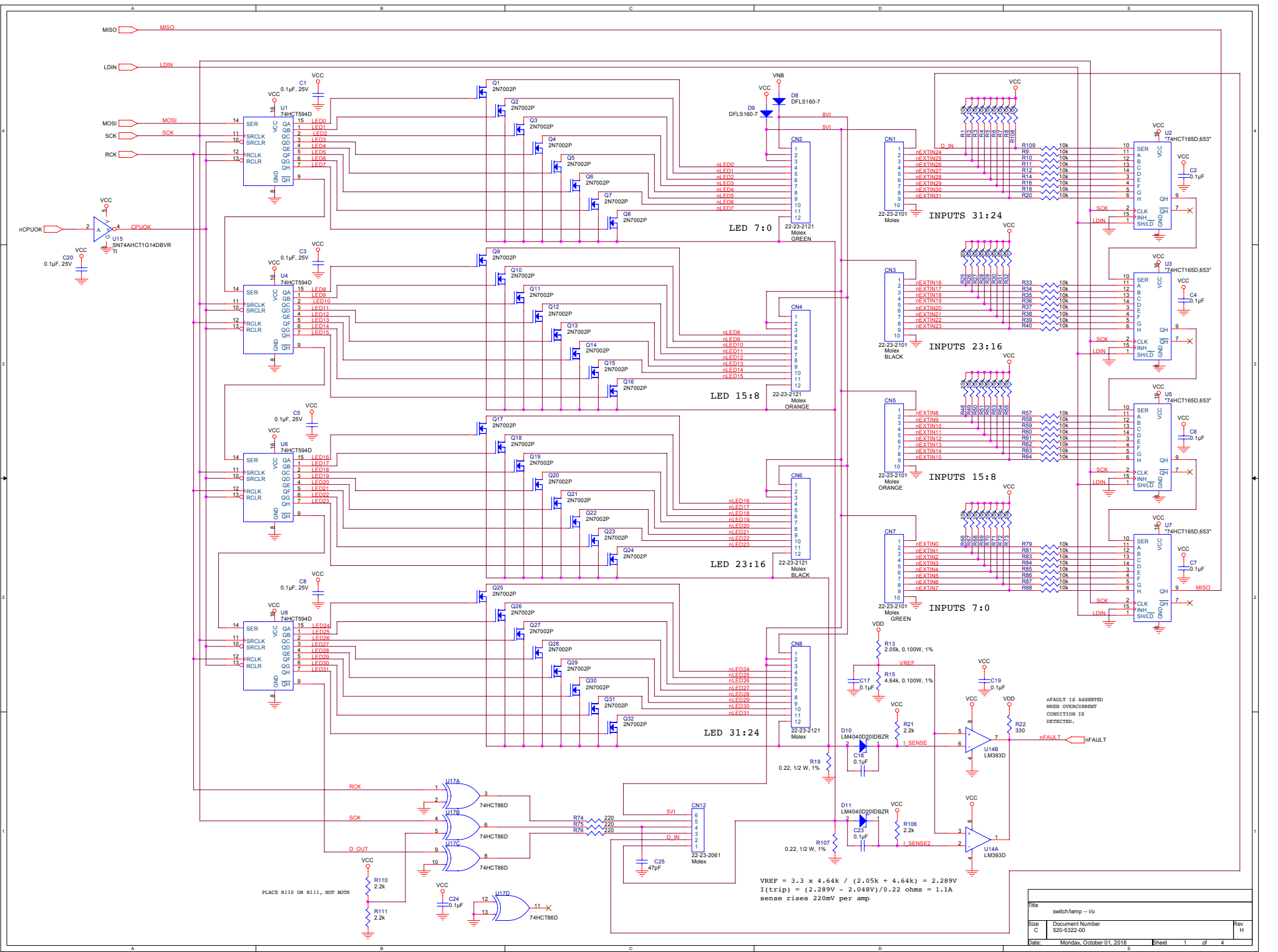


STERN SPIKE SYSTEM SCHEMATICS

Released February 2019





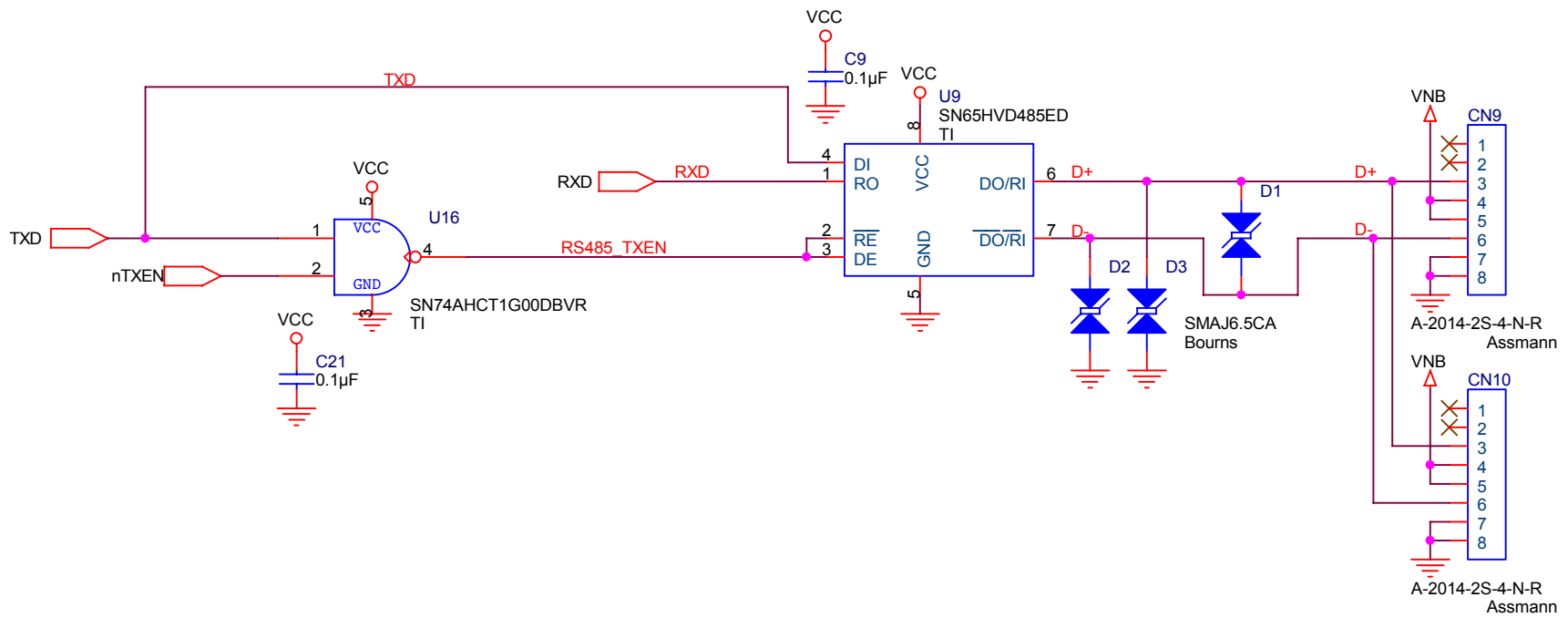
PLACE R110 OR R111, NOT BOTH

$$VREF = 3.3 \times 4.64k / (2.05k + 4.64k) = 2.289V$$

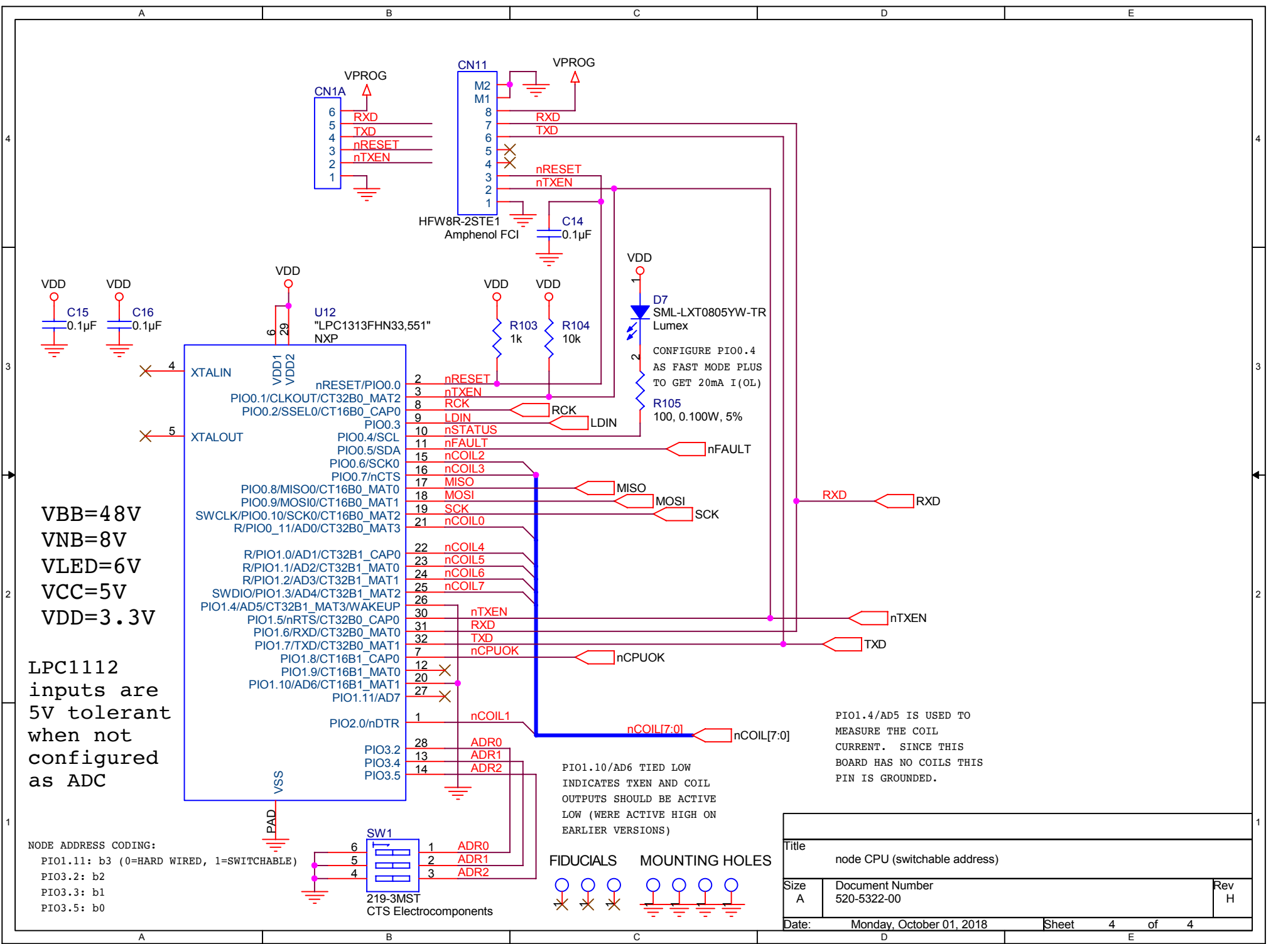
$$I(trip) = (2.289V - 2.048V) / 0.22 \text{ ohms} = 1.1A$$

sense rises 220mV per amp

Title	switch/lamp - i/o	Rev	H
Size	Document Number		
C	520-5322-00		
Date:	Monday, October 01, 2018	Sheet	1 of 4



Title		
switch/lamp -- communication		
Size	Document Number	Rev
A	520-5322-00	H
Date:	Monday, October 01, 2018	Sheet 2 of 4



VBB=48V
 VNB=8V
 VLED=6V
 VCC=5V
 VDD=3.3V

LPC1112
 inputs are
 5V tolerant
 when not
 configured
 as ADC

NODE ADDRESS CODING:
 PIO1.11: b3 (0=HARD WIRED, 1=SWITCHABLE)
 PIO3.2: b2
 PIO3.3: b1
 PIO3.5: b0

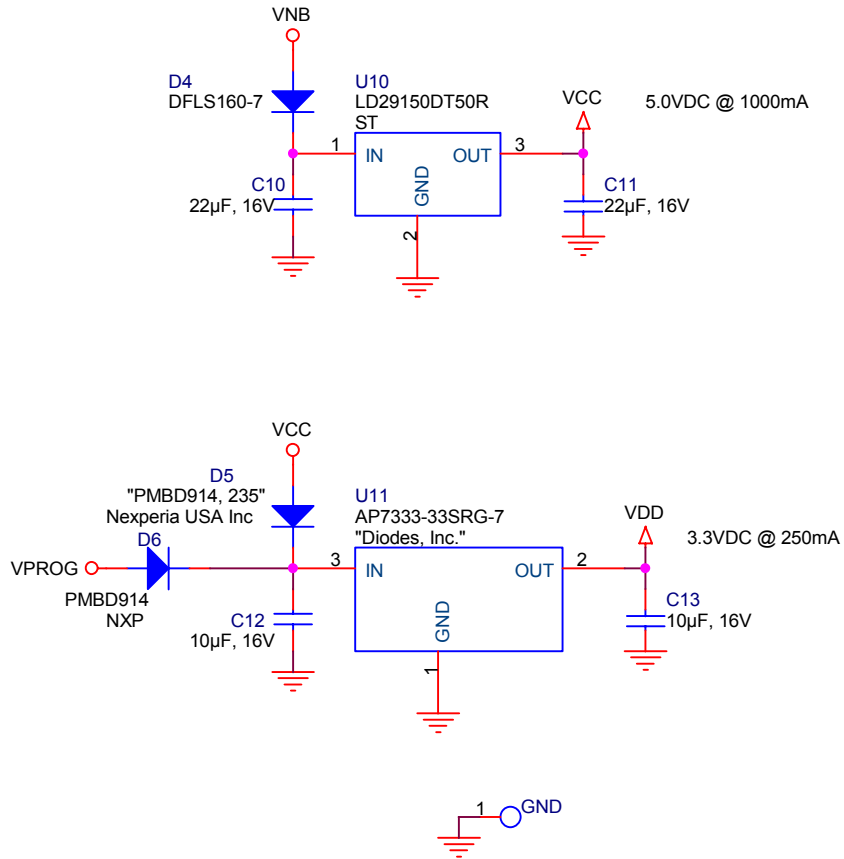
PIO1.10/AD6 TIED LOW
 INDICATES TXEN AND COIL
 OUTPUTS SHOULD BE ACTIVE
 LOW (WERE ACTIVE HIGH ON
 EARLIER VERSIONS)

PIO1.4/AD5 IS USED TO
 MEASURE THE COIL
 CURRENT. SINCE THIS
 BOARD HAS NO COILS THIS
 BOARD HAS NO COILS THIS
 BOARD HAS NO COILS THIS
 BOARD HAS NO COILS THIS
 BOARD HAS NO COILS THIS
 BOARD HAS NO COILS THIS

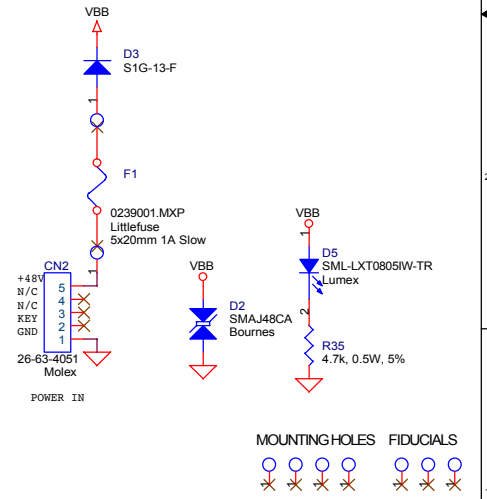
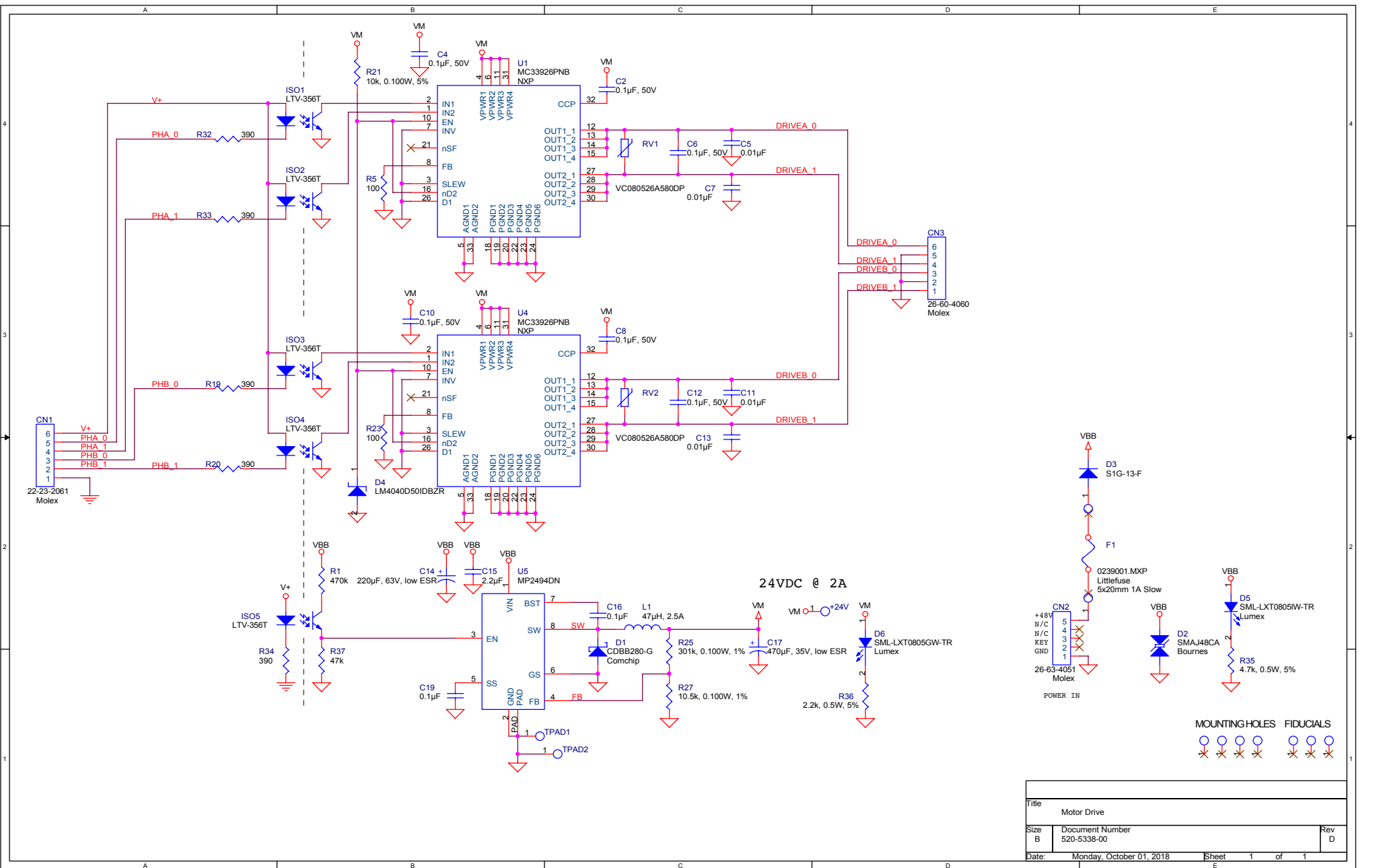
Title		
node CPU (switchable address)		
Size	Document Number	Rev
A	520-5322-00	H
Date:	Monday, October 01, 2018	Sheet 4 of 4

STATUS LED (D7, YELLOW)

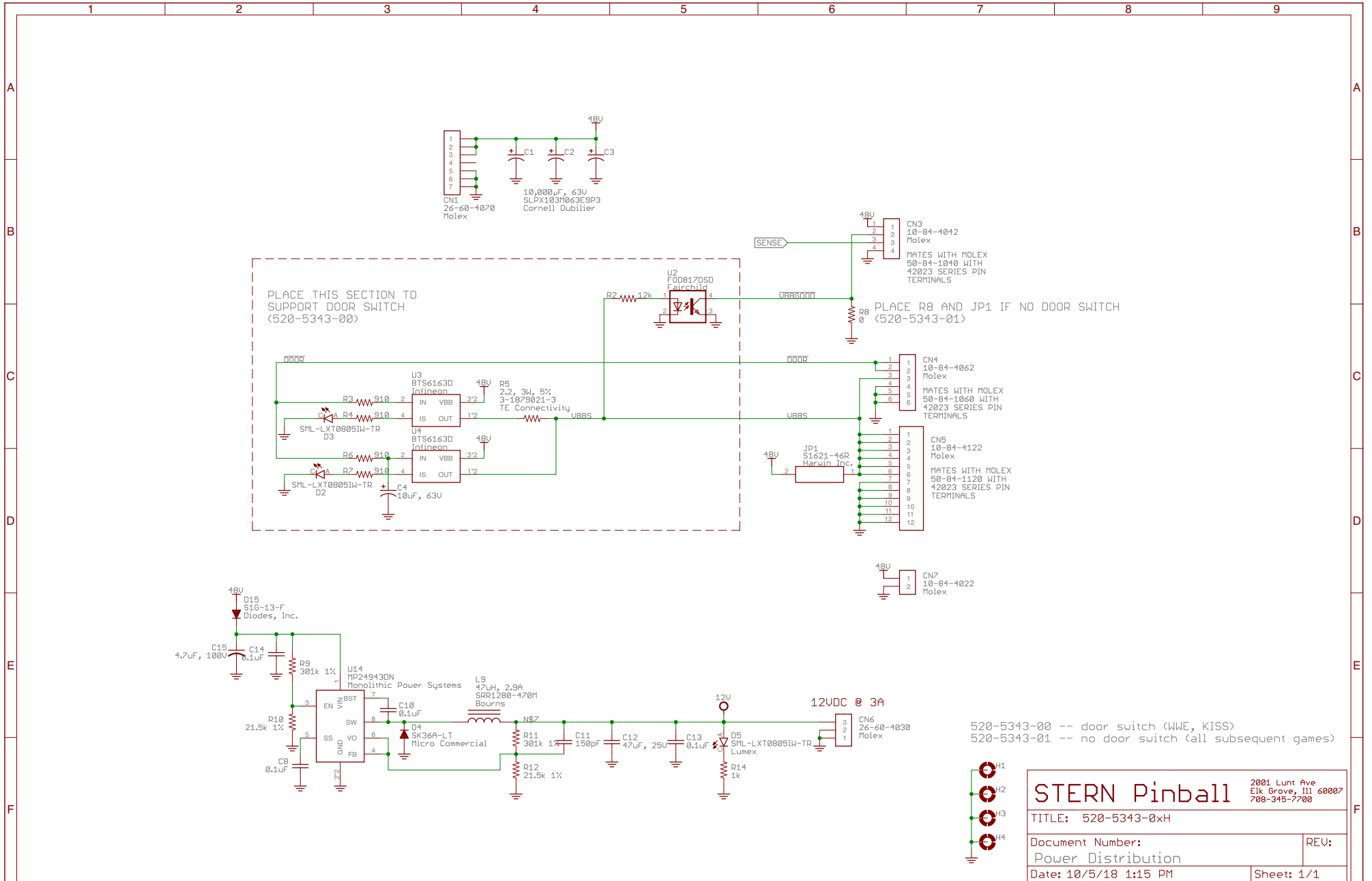
10Hz 50% power okay, processor in boot mode waiting for runtime update: check node cable, ensure other nodes are communicating, check communication interface
 1Hz 90% power okay, processor in runtime mode but not receiving from CPU: check node cable, ensure other nodes are communicating, check communication interface
 flickering power okay, processor communicating and operating correctly

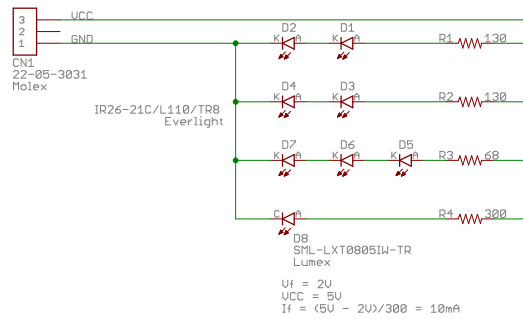


Title		
switch/lamp -- power supply		
Size	Document Number	Rev
A	520-5322-00	H
Date:	Monday, October 01, 2018	Sheet 3 of 4



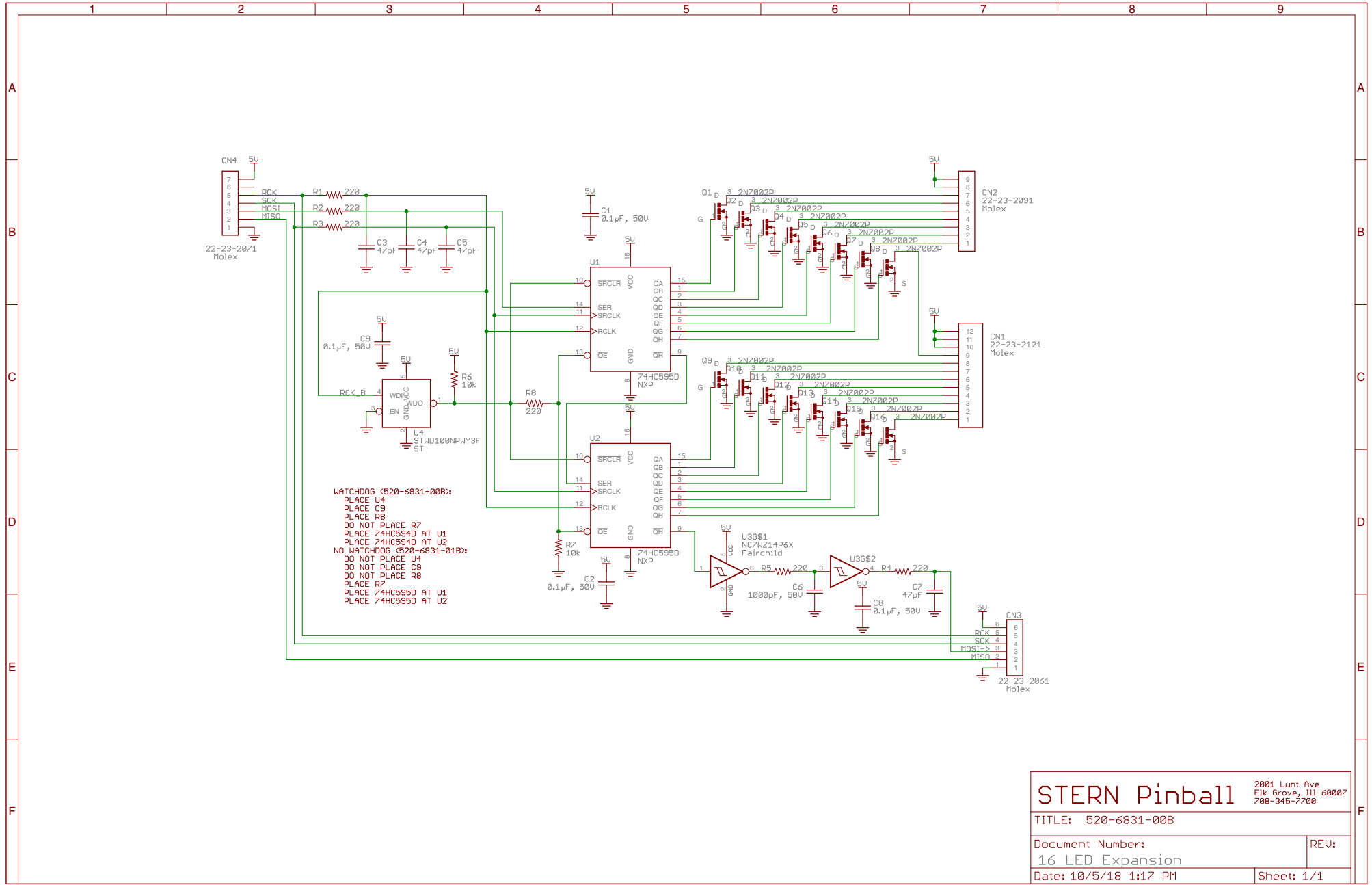
Title		
Motor Drive		
Size	Document Number	Rev
B	520-5338-00	D
Date:	Monday, October 01, 2018	Sheet 1 of 1



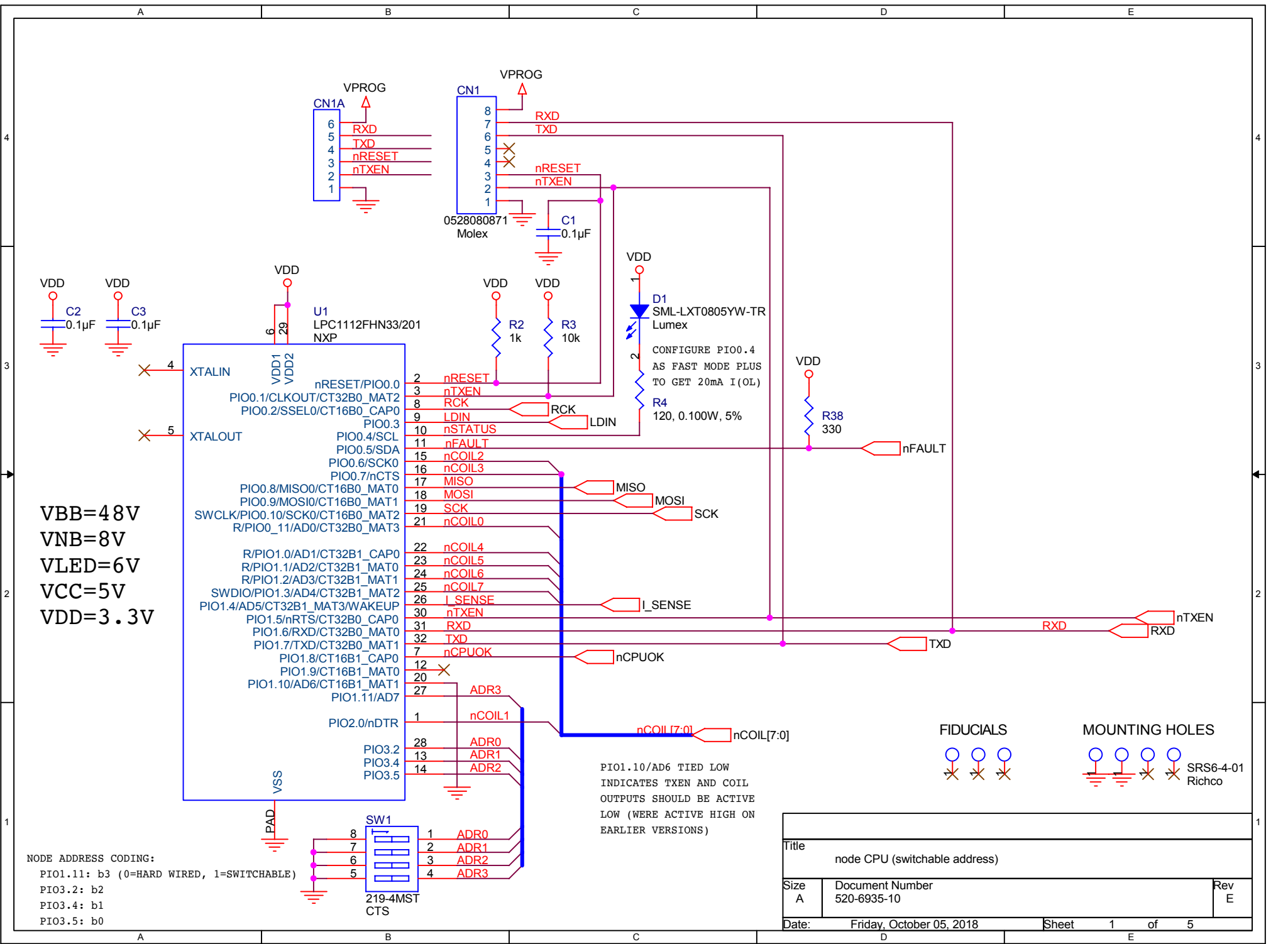


$V_f = 1.2V$
 $UCC = 5V$
 $I_f = 20mA$
 two LEDs: $R = (5V - (2 \times 1.2V))/130\Omega = 20mA$
 three LEDs: $R = (5V - (3 \times 1.2V))/68\Omega = 20mA$

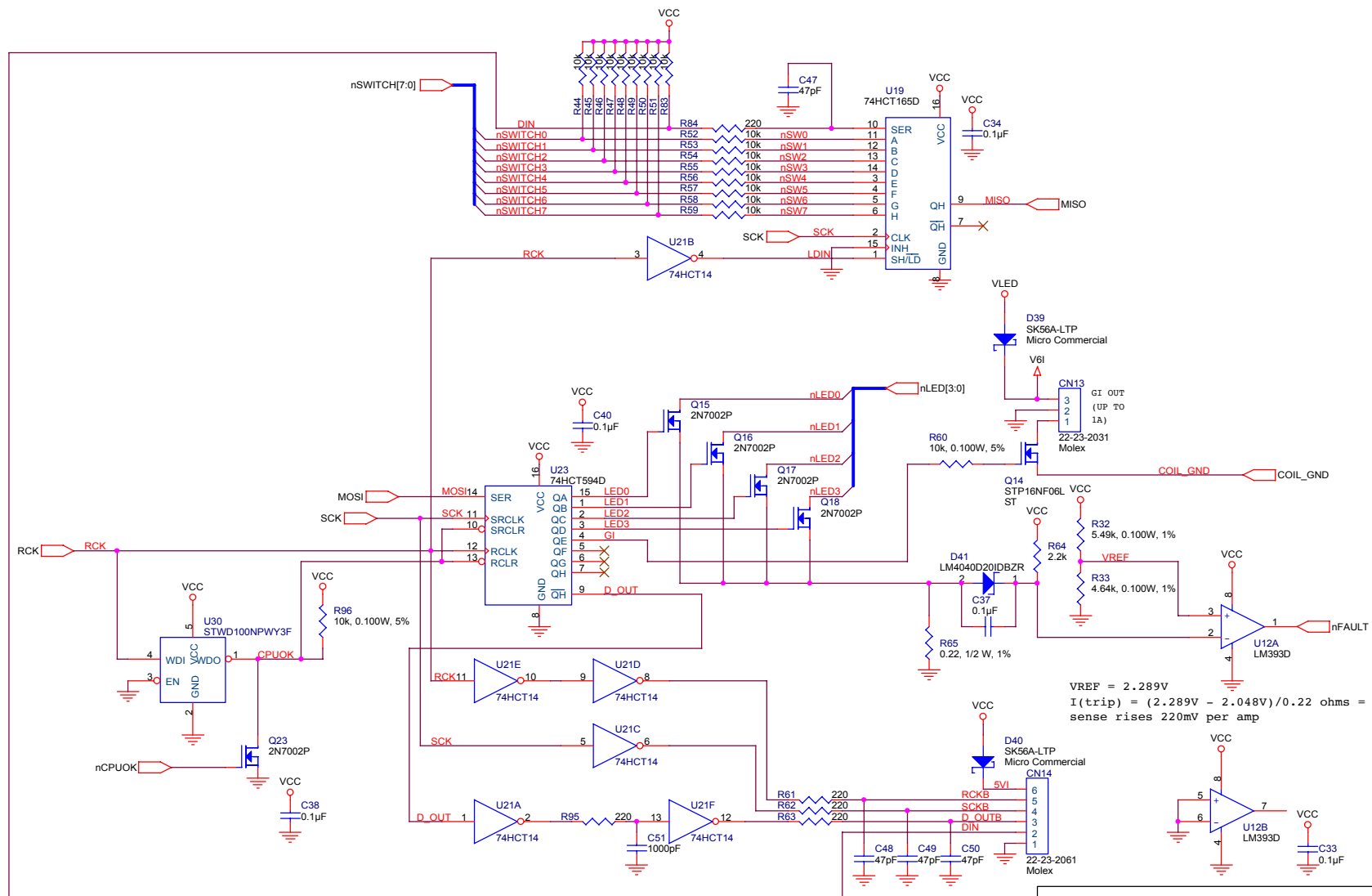
STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
		TITLE: 520-5344-00E	
Document Number:		REV:	
Trough Emitters		E	
Date: 10/5/18 1:16 PM		Sheet: 1/1	



STERN Pinball 2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700		TITLE: 520-6831-00B	
		Document Number:	REV:
Date: 10/5/18 1:17 PM		Sheet: 1/1	



NODE ADDRESS CODING:
 PIO1.11: b3 (0=HARD WIRED, 1=SWITCHABLE)
 PIO3.2: b2
 PIO3.4: b1
 PIO3.5: b0

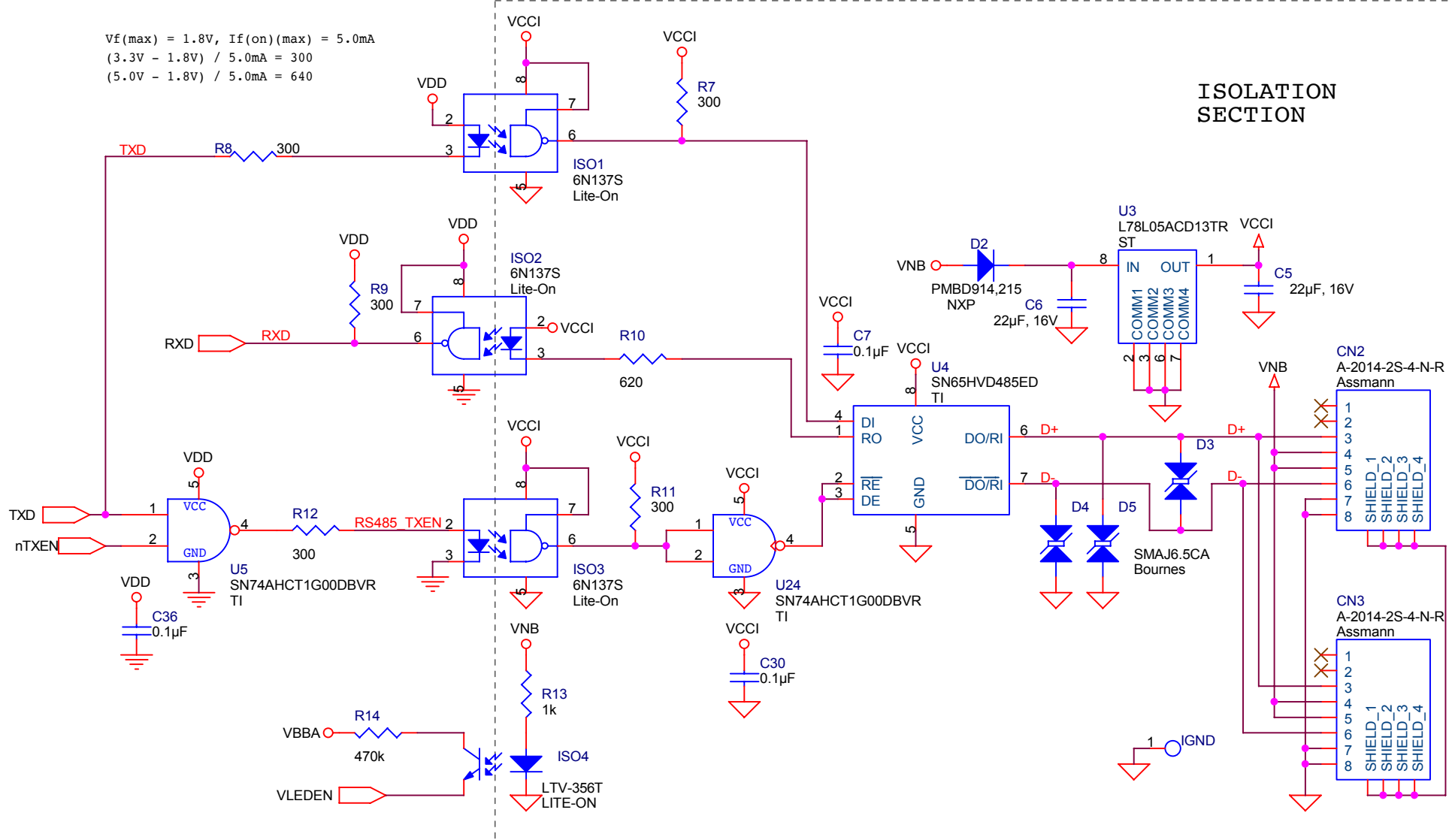


$V_{REF} = 2.289V$
 $I(\text{trip}) = (2.289V - 2.048V) / 0.22 \text{ ohms} = 1.1A$
 sense rises 220mV per amp

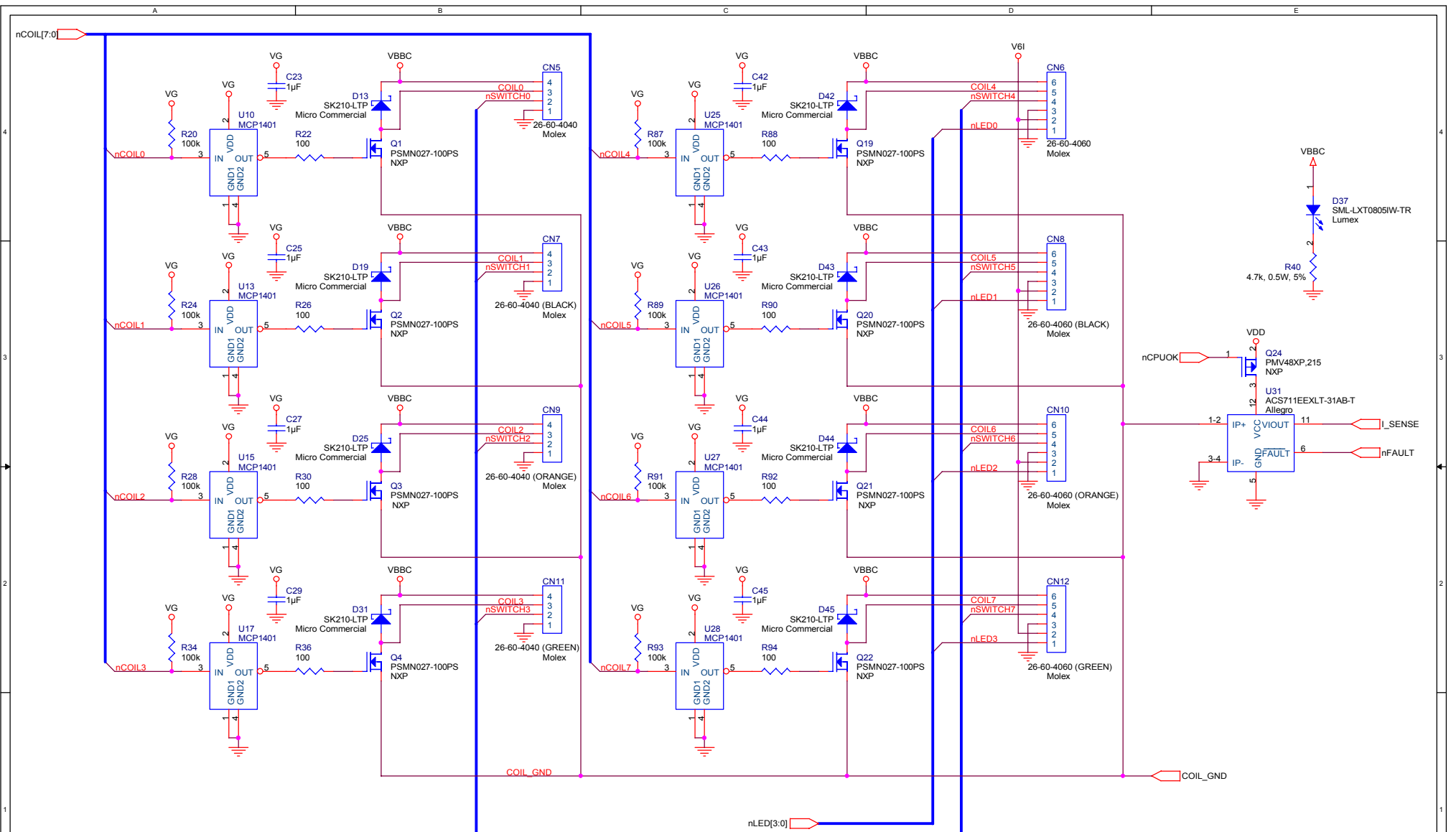
Title		
io		
Size	Document Number	Rev
B	520-6935-10	E
Date:	Friday, October 05, 2018	Sheet 5 of 5

$V_f(\max) = 1.8V$, $I_f(\text{on})(\max) = 5.0mA$
 $(3.3V - 1.8V) / 5.0mA = 300$
 $(5.0V - 1.8V) / 5.0mA = 640$

ISOLATION SECTION



Title		
communication -- isolated		
Size	Document Number	Rev
A	520-6935-10	E
Date:	Friday, October 05, 2018	Sheet 2 of 5



nSWITCH[7:0]

I_SENSE rises 33mV/A from its idle voltage of 1.225V. ADC should idle at about 380 (10-bit) and will rise by 10.24 per amp as coil current increases (e.g, 10A coil current should read 380 + 10 x 10.24 = 482).

$$I_SENSE = 1.225V + I(\text{coil}) \times 0.033 \text{ ohms}$$

$$VREF = 5.00V \times 4.64k / (5.49k + 4.64k) = 2.290V$$

$$I(\text{trip}) = (2.290V - 1.225V) / 0.033 \text{ ohms} = 32A$$

Title		
coils		
Size	Document Number	Rev
B	520-6935-10	E
Date:	Friday, October 05, 2018	Sheet 4 of 5

LED STATUS TABLE

48V 6V MCU STATUS

D37 D10 D1

RED GREEN YELLOW

OFF OFF OFF

48V not present: check that system is connected and powered

ON OFF OFF

48V present, no 6V: node bus is powered off by CPU, node bus cable is unplugged, or 6V supply is overloaded (shorted) or damaged

ON ON OFF

48V present, 6V present, processor not running: check 5V and 3.3V supplies

ON ON 10Hz 50%

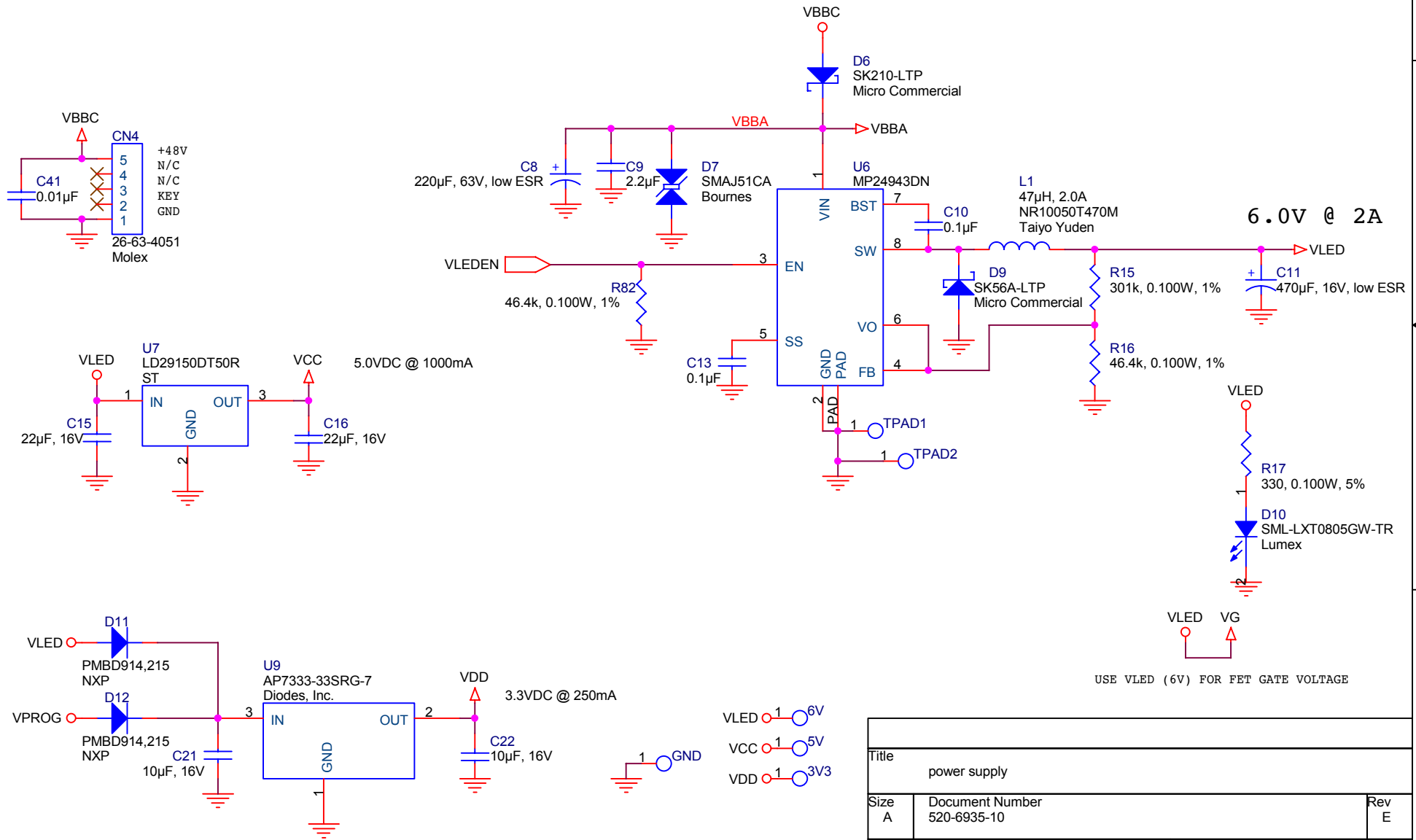
power okay, processor in boot mode waiting for runtime update: check node cable, ensure other nodes are communicating, check communication interface

ON ON 1Hz 90%

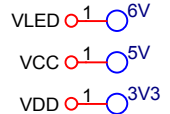
power okay, processor in runtime mode but not receiving from CPU: check node cable, ensure other nodes are communicating, check communication interface

ON ON flickering

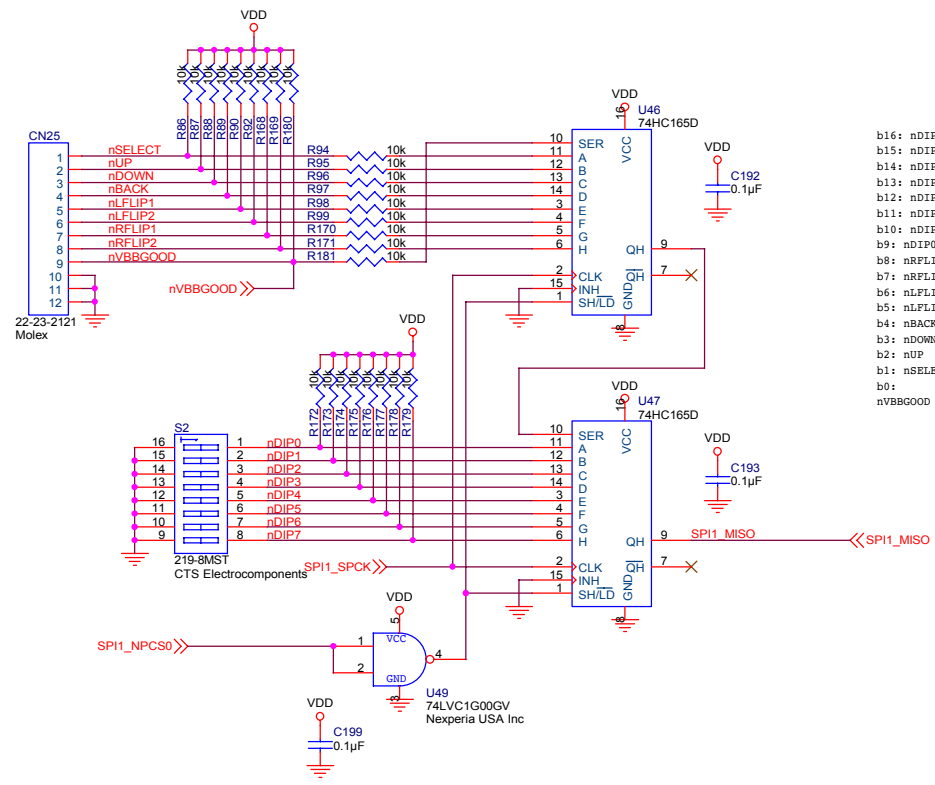
power okay, processor communicating and operating correctly



USE VLED (6V) FOR FET GATE VOLTAGE

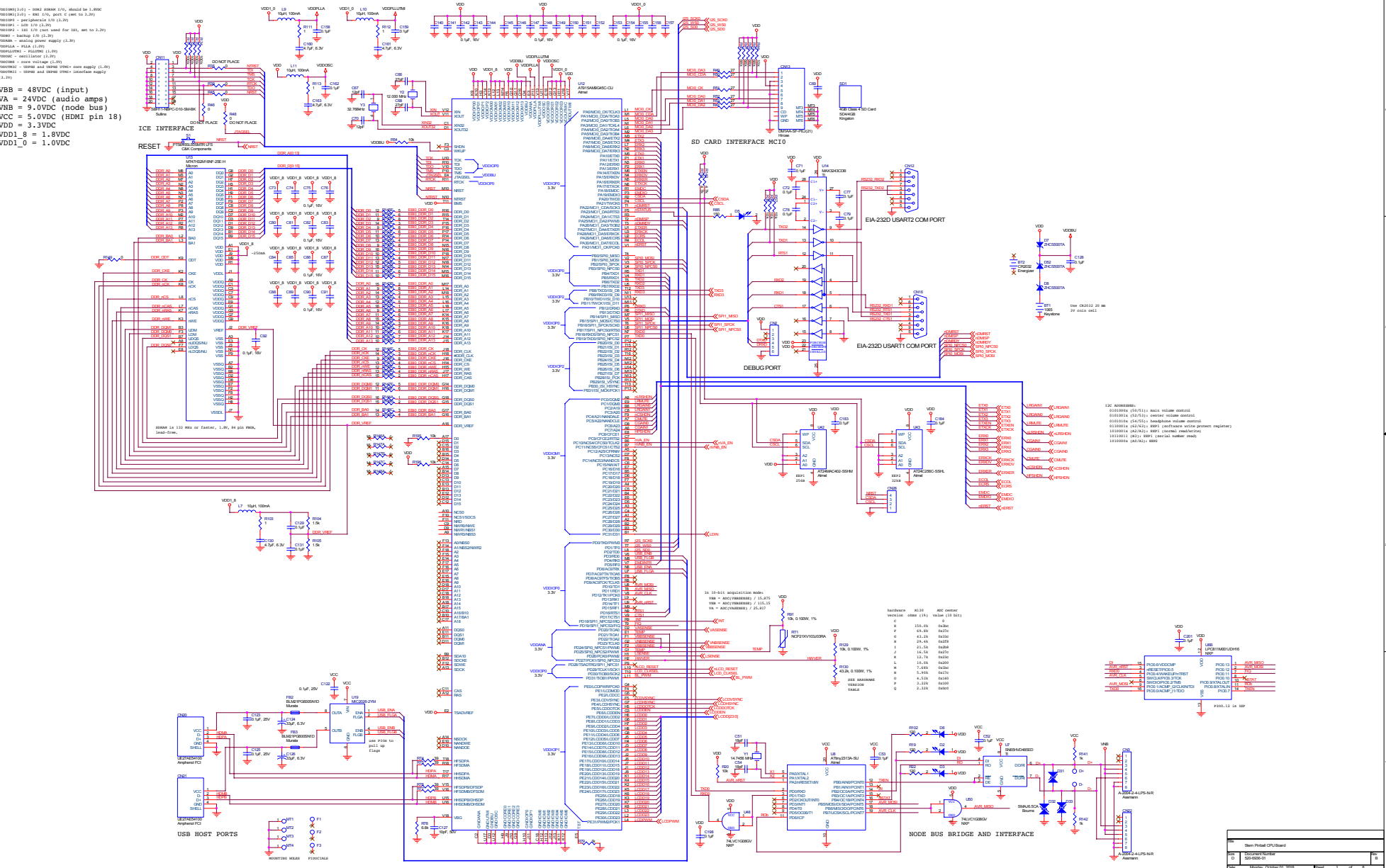


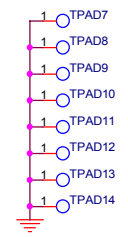
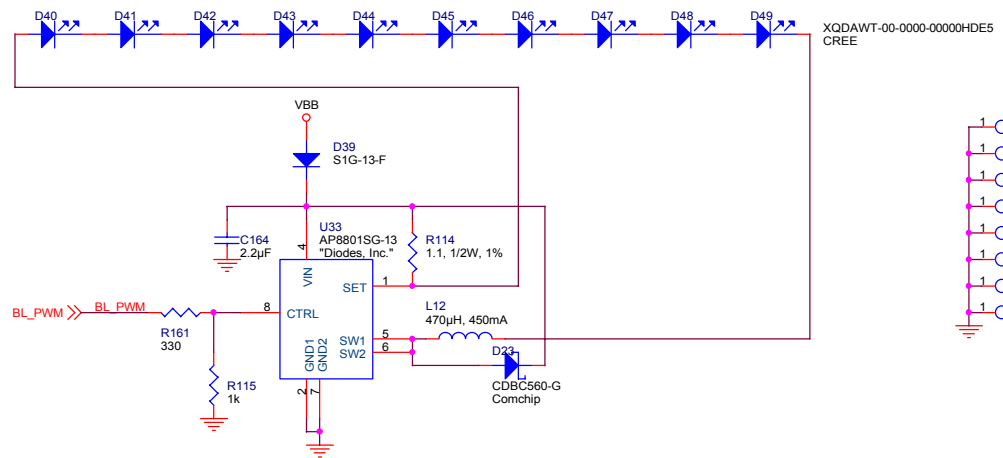
Title		
power supply		
Size	Document Number	Rev
A	520-6935-10	E
Date:	Friday, October 05, 2018	Sheet 3 of 5



- b16: nDIP7
- b15: nDIP6
- b14: nDIP5
- b13: nDIP4
- b12: nDIP3
- b11: nDIP2
- b10: nDIP1
- b9: nDIP0
- b8: nRFLIP2
- b7: nRFLIP1
- b6: nLFLIP2
- b5: nLFLIP1
- b4: nBACK
- b3: nDOWN
- b2: nUP
- b1: nSELECT
- b0: nVBBGOOD

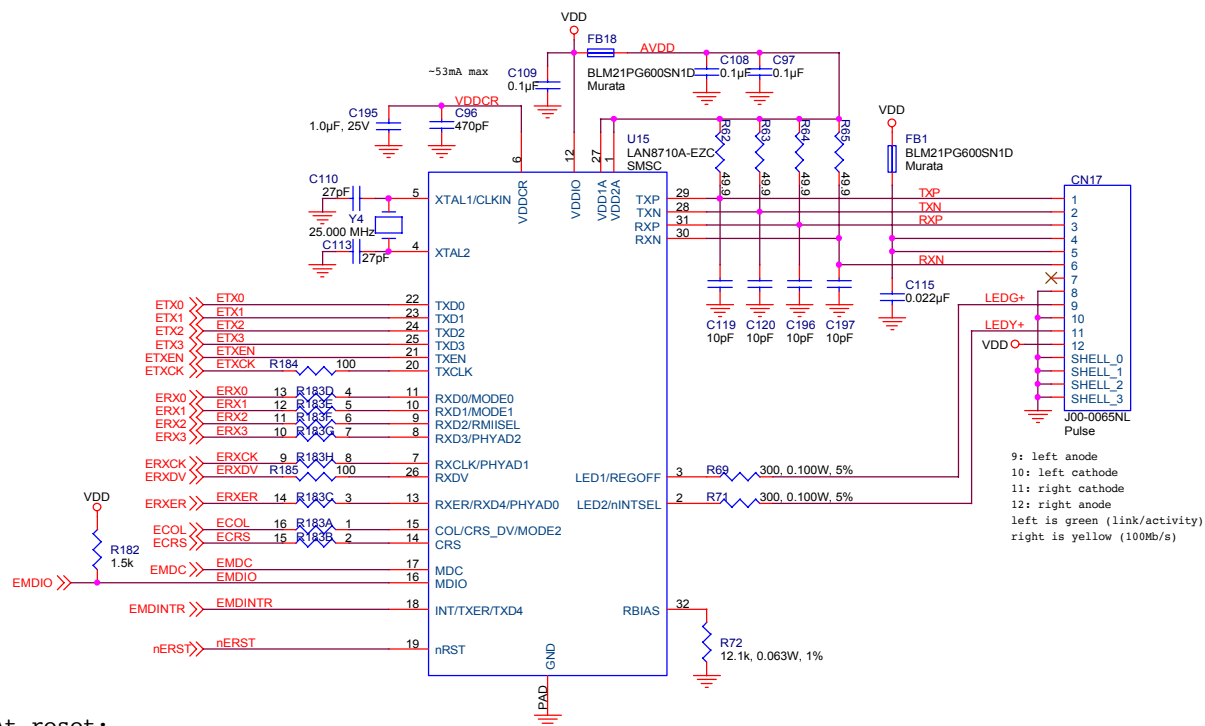
Title		
Stern Pinball CPU -- switch inputs		
Size	Document Number	Rev
B	520-6936-01	B
Date:	Monday, October 01, 2018	Sheet 2 of 8





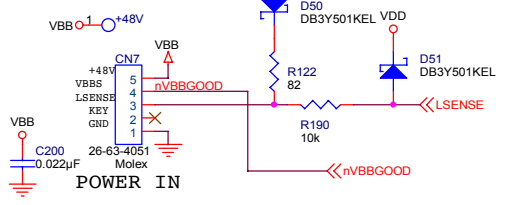
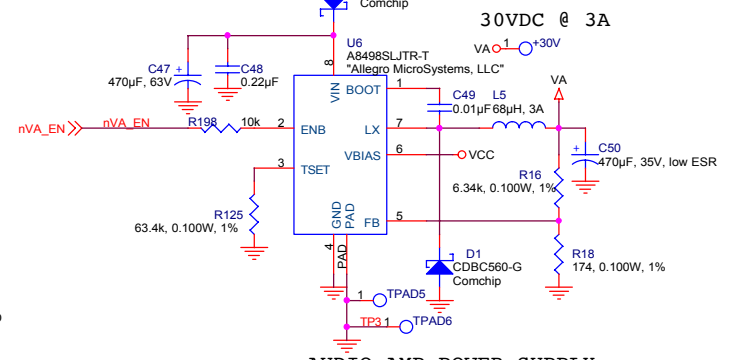
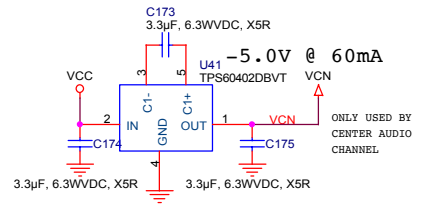
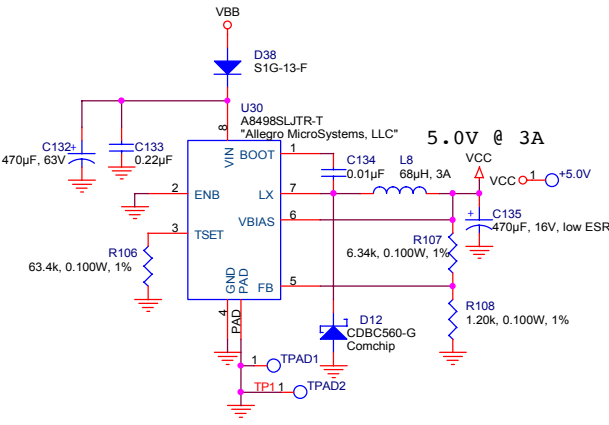
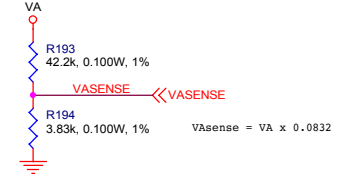
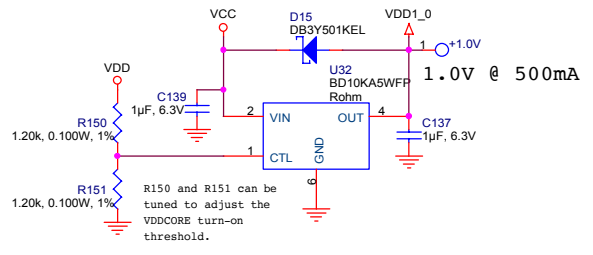
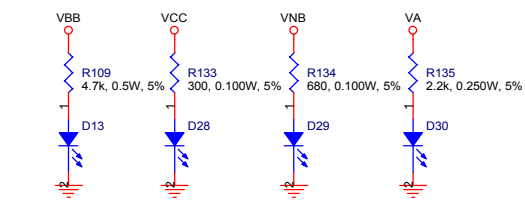
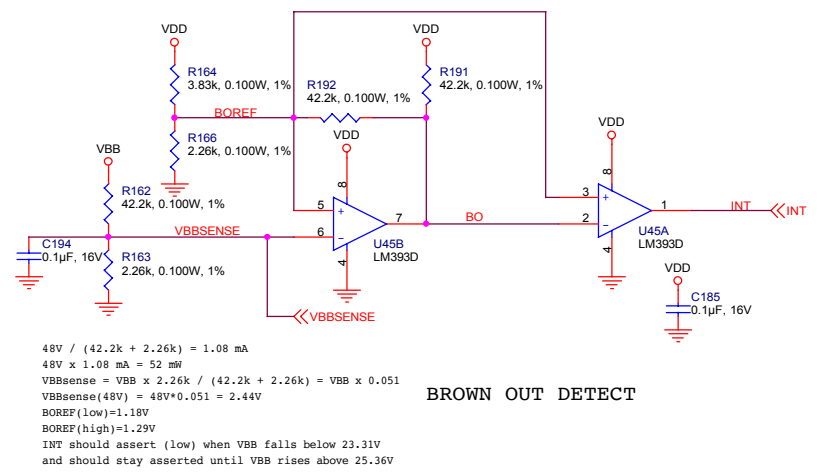
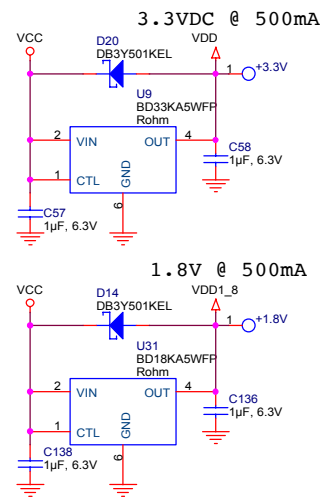
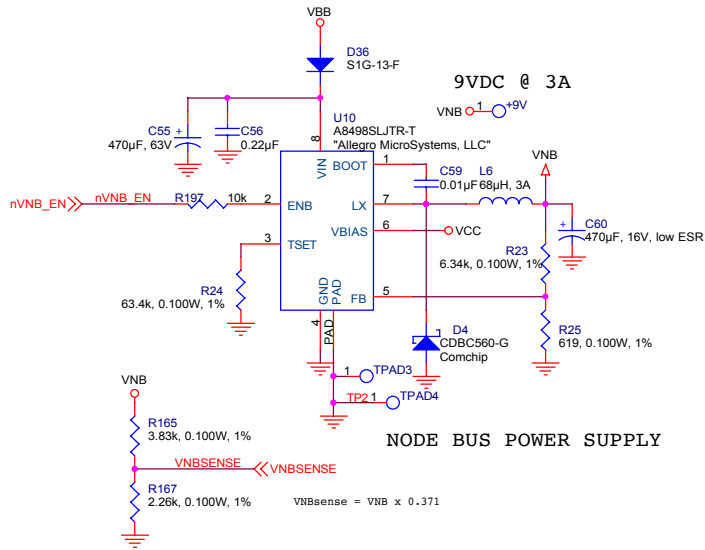
$V_{thd} = 200 \text{ mV}$
 $V_{ref} = 1.25\text{V}$
 $I_{led} = V_{ctrl} / V_{ref} \times V_{thd} / R_{set}$
 $V_{ctrl} = 3.3 \times 1\text{k} / (330 + 1\text{k}) = 2.48\text{V}$
 $I_{led} (\text{target}) = 350 \text{ mA}$
 $R_{set} = V_{ctrl} / V_{ref} \times V_{thd} / I_{led} = 2.48\text{V} / 1.25\text{V} \times 200\text{mV} / 350\text{mA} = 1.13 \text{ ohms}$
 $R_{set} = 1.1 \text{ ohms}$
 $I_{led} = 2.48 / 1.25 \times 200\text{mV} / 1.1 \text{ ohms} = 360 \text{ mA}$
 Power across Rset is $(I^2)R = (360\text{mA})^2 \times 1.1 \text{ ohms} = 143\text{mW}$

Title		backlight	
Size	Document Number	Rev	
B	520-6936-01	B	
Date:	Monday, October 01, 2018	Sheet	4 of 8

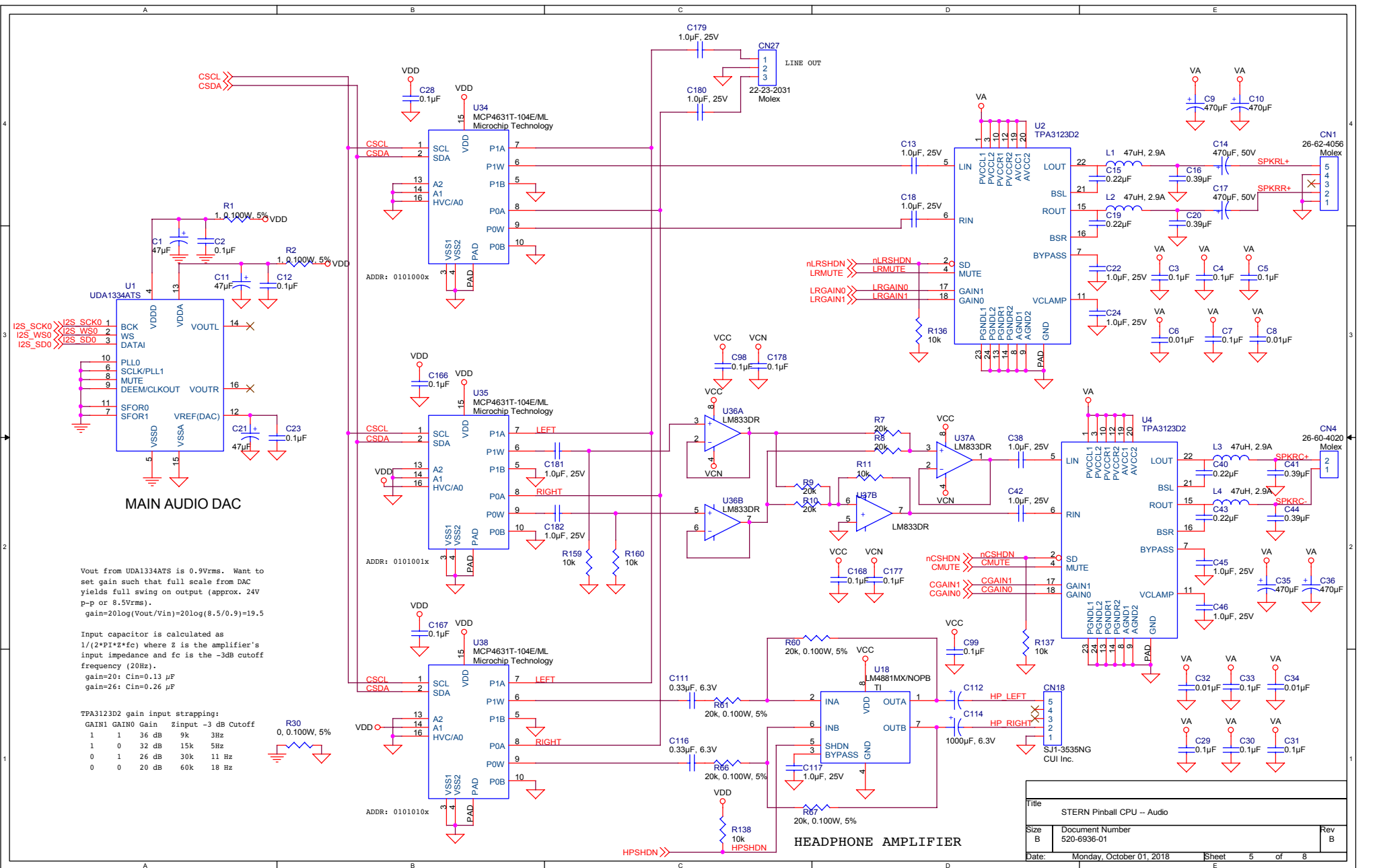


9: left anode
 10: left cathode
 11: right cathode
 12: right anode
 left is green (link/activity)
 right is yellow (100Mb/s)

Title			Ethernet interface		
Size	Document Number				Rev
B	520-6936-01				B
Date:	Monday, October 01, 2018	Sheet	7	of	8



Title		
STERN Pinball CPU -- power supply		
Size	Document Number	Rev
B	520-6936-01	B
Date:	Monday, October 01, 2018	Sheet 6 of 8



MAIN AUDIO DAC

Vout from UDA1334ATS is 0.9Vrms. Want to set gain such that full scale from DAC yields full swing on output (approx. 24V p-p or 8.5Vrms).
 $gain = 20 \log(V_{out}/V_{in}) = 20 \log(8.5/0.9) = 19.5$

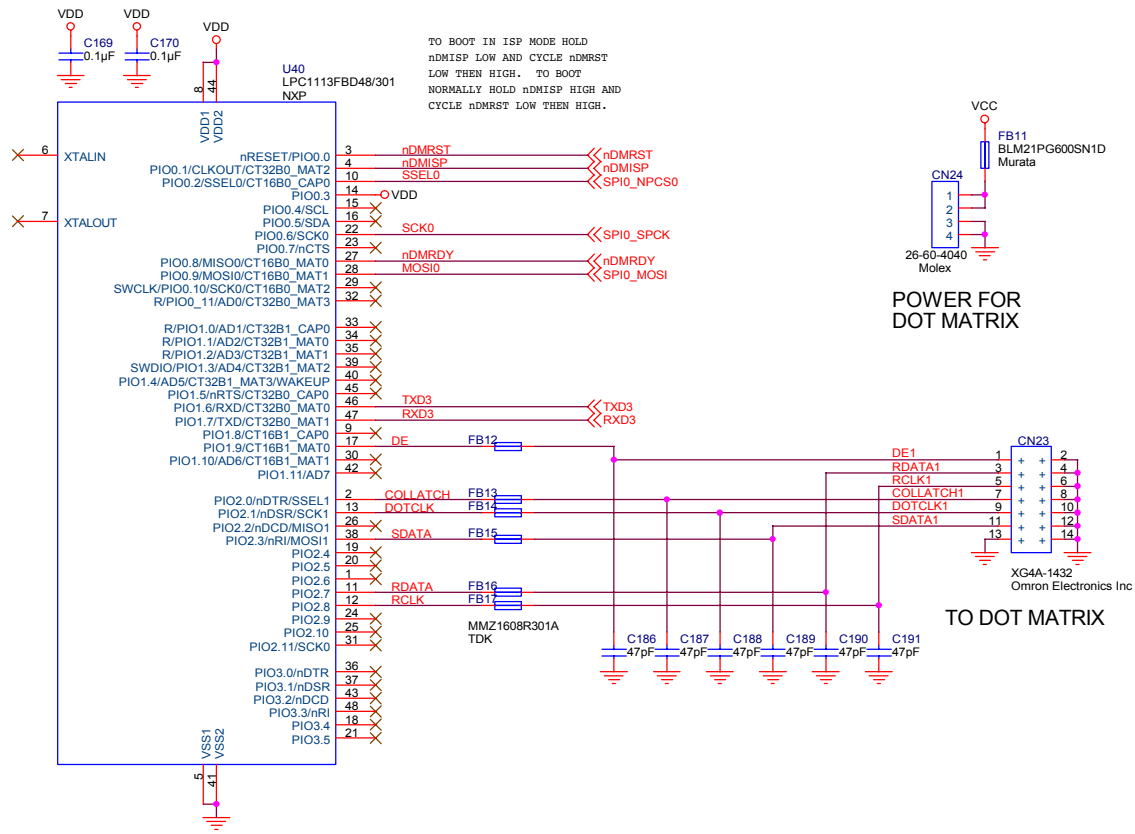
Input capacitor is calculated as $1/(2 * \pi * Z * f_c)$ where Z is the amplifier's input impedance and f_c is the -3dB cutoff frequency (20Hz).
 $gain = 20; C_{in} = 0.13 \mu F$
 $gain = 26; C_{in} = 0.26 \mu F$

TPA3123D2 gain input strapping:

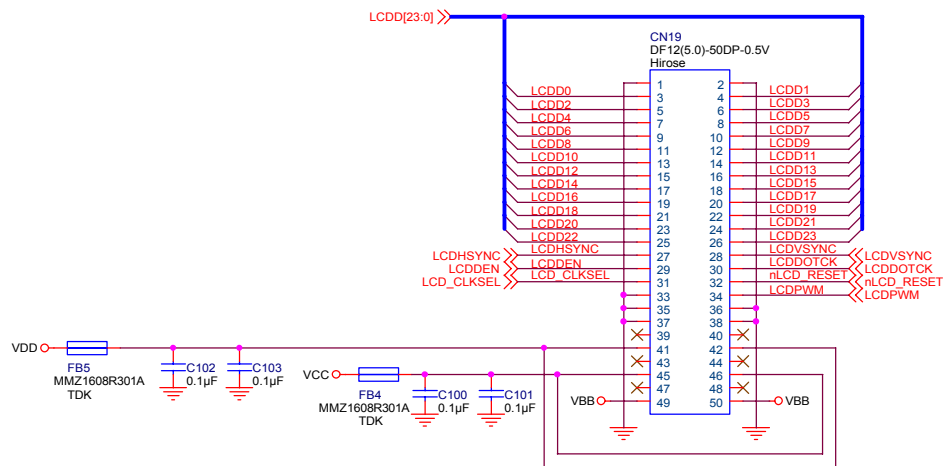
GAIN1	GAIN0	Gain	Z _{input}	-3 dB Cutoff
1	1	36 dB	9k	3Hz
1	0	32 dB	15k	5Hz
0	1	26 dB	30k	11 Hz
0	0	20 dB	60k	18 Hz

HEADPHONE AMPLIFIER

Title		
STERN Pinball CPU - Audio		
Size	Document Number	Rev
B	520-6936-01	B
Date:	Monday, October 01, 2018	Sheet 5 of 8



Title		
dot matrix display interface		
Size	Document Number	Rev
B	520-6936-01	B
Date:	Monday, October 01, 2018	Sheet 8 of 8



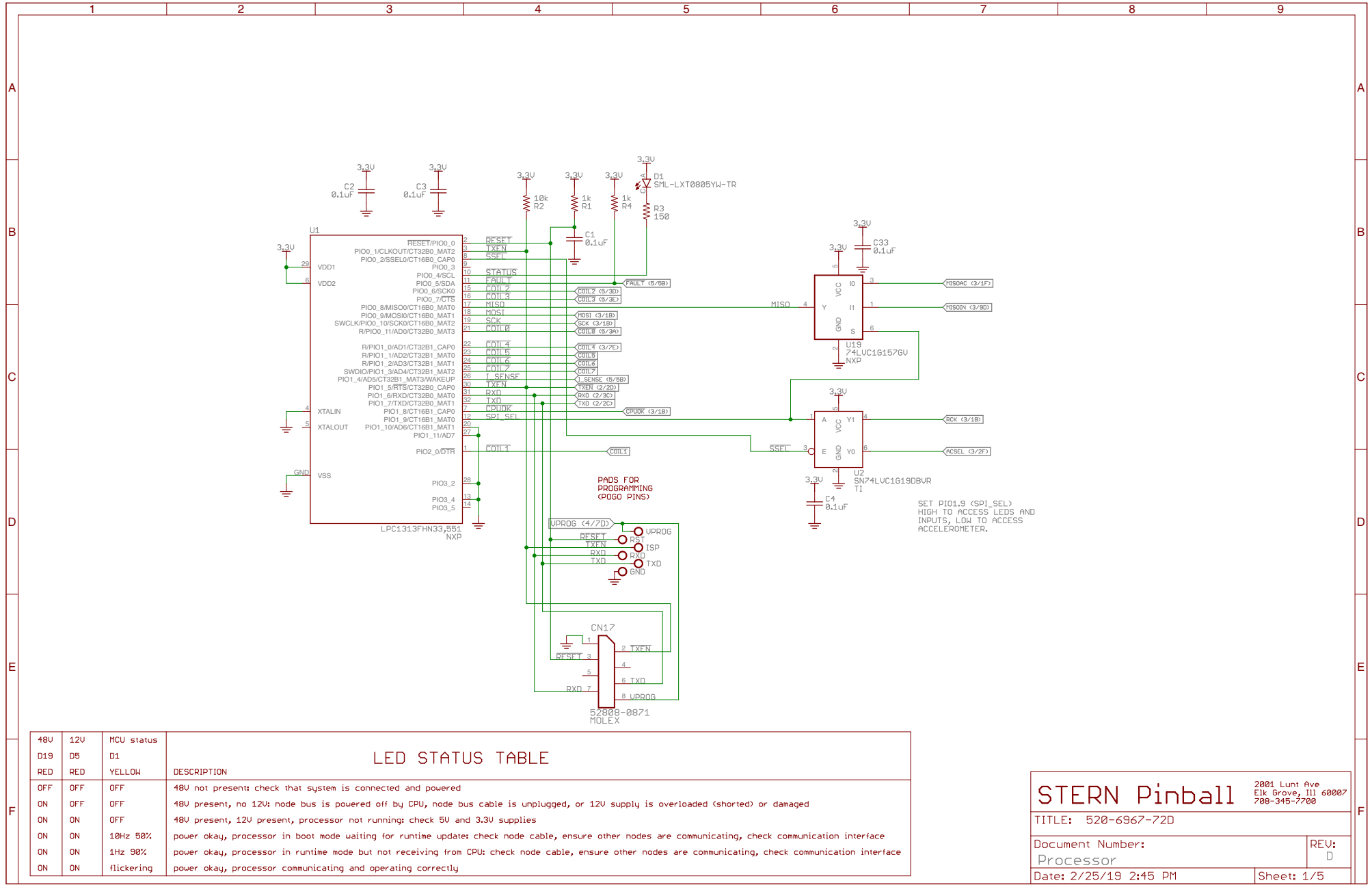
USE KEYSTONE 24390 5.0mm M3
SPACER OR EQUIVALENT

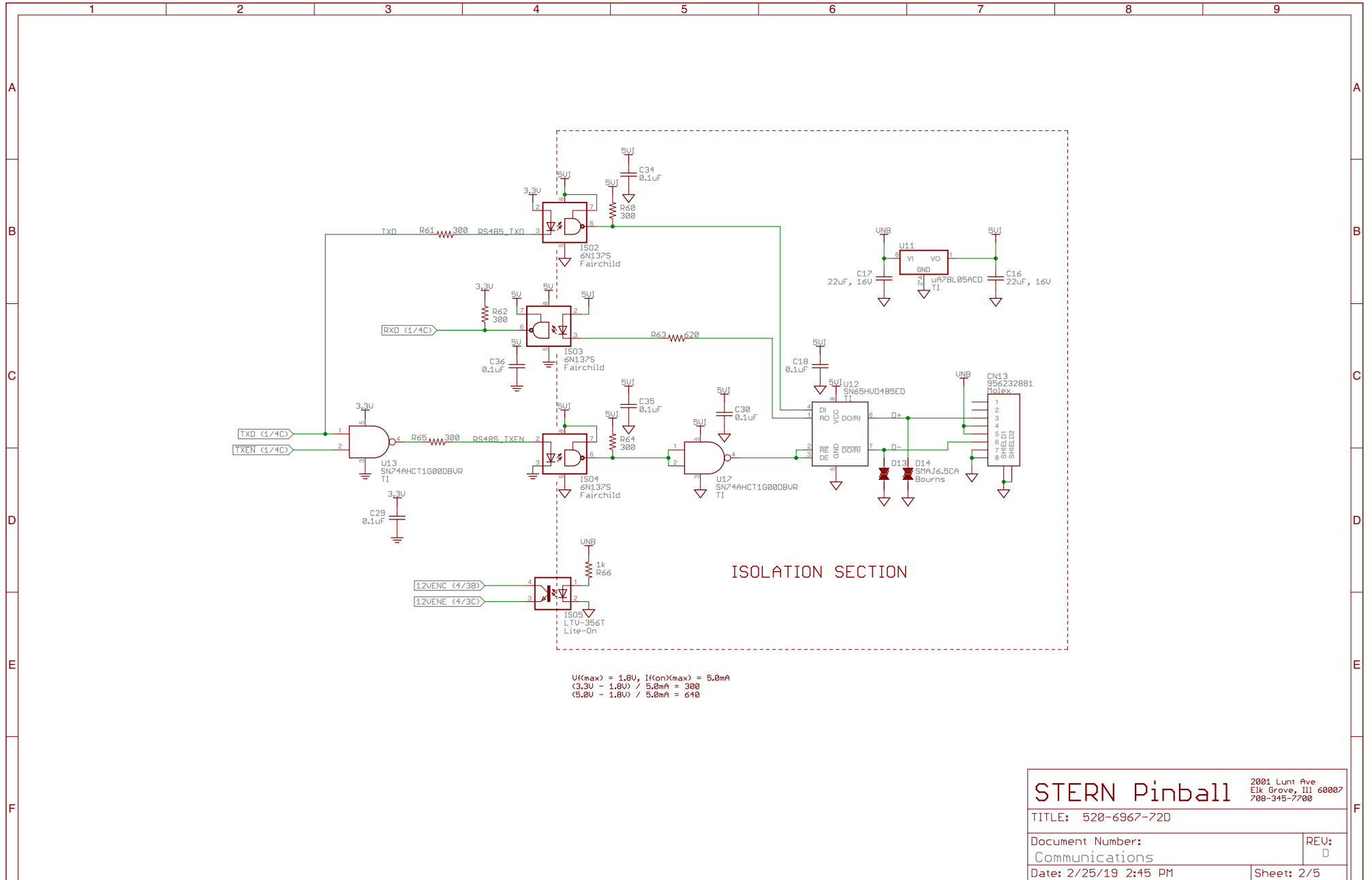


LCDD7:0 = RED
LCDD15:8 = GREEN
LCDD23:16 = BLUE

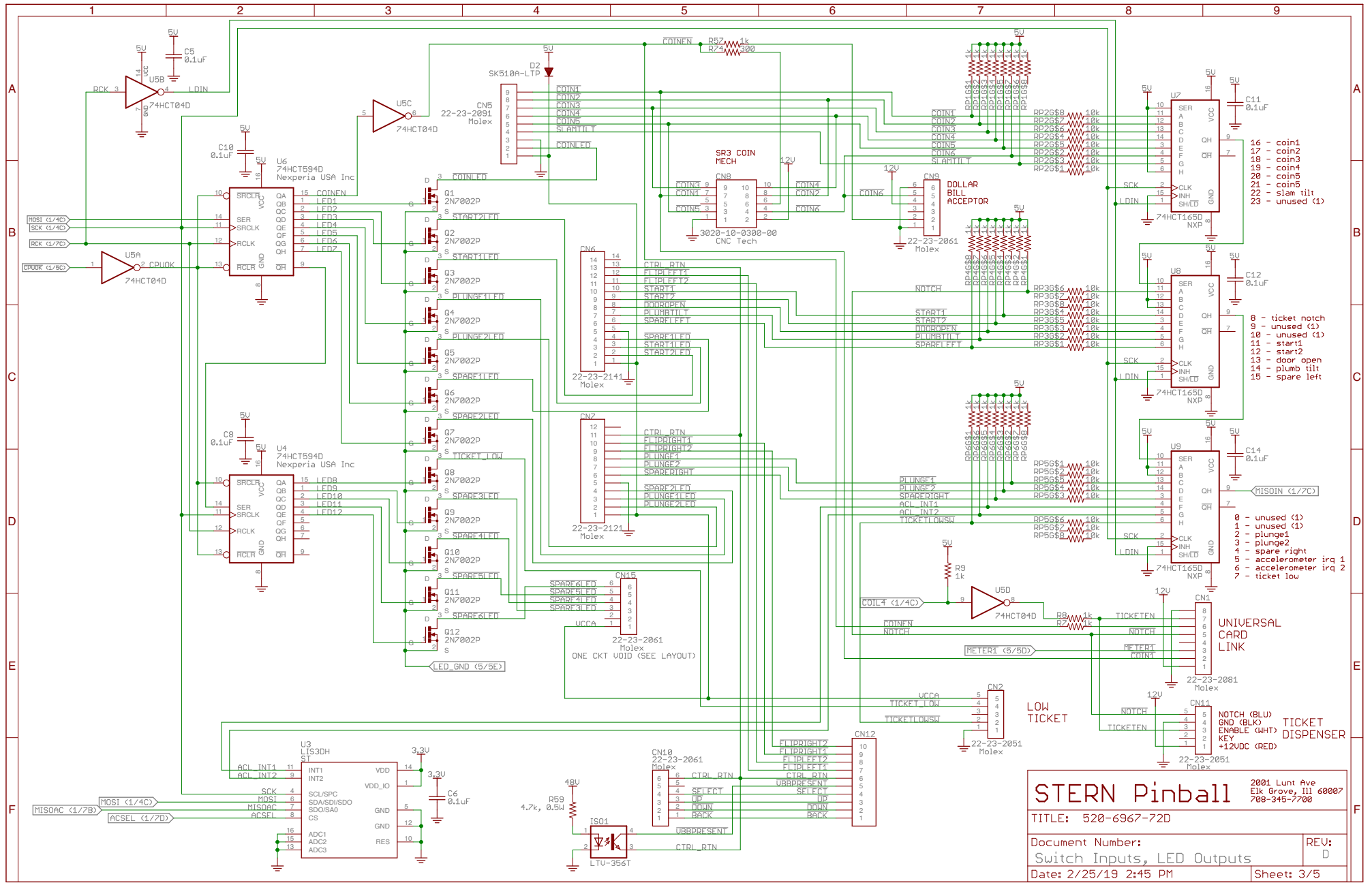
COLOR DATA IS ALWAYS TOP-JUSTIFIED
(e.g., IF ONLY FIVE BITS OF RED ARE
USED THEY ARE MAPPED TO LCDD7:3)

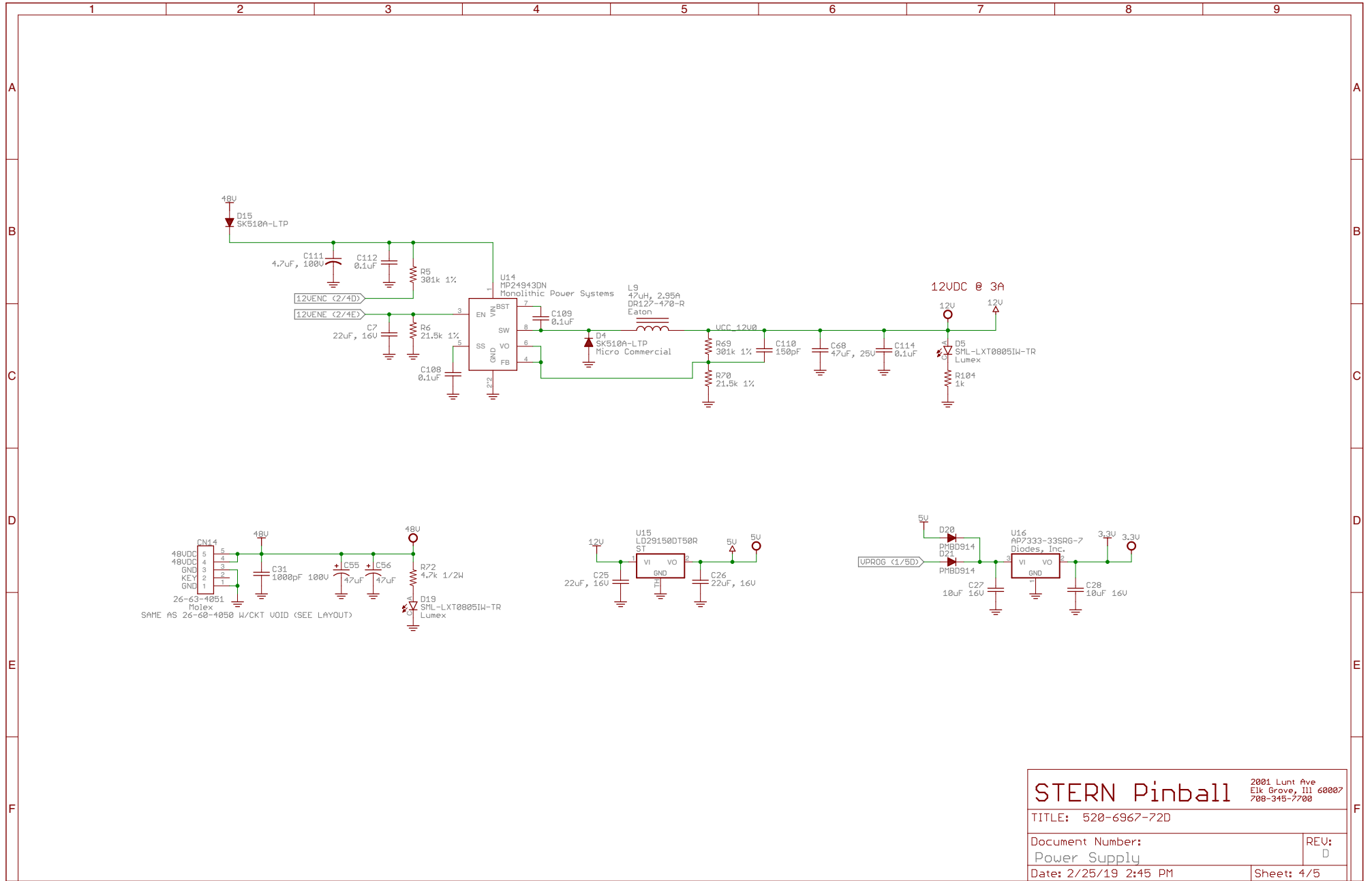
Title		
video interface		
Size	Document Number	Rev
B	520-6936-01	B
Date:	Monday, October 01, 2018	Sheet 3 of 8



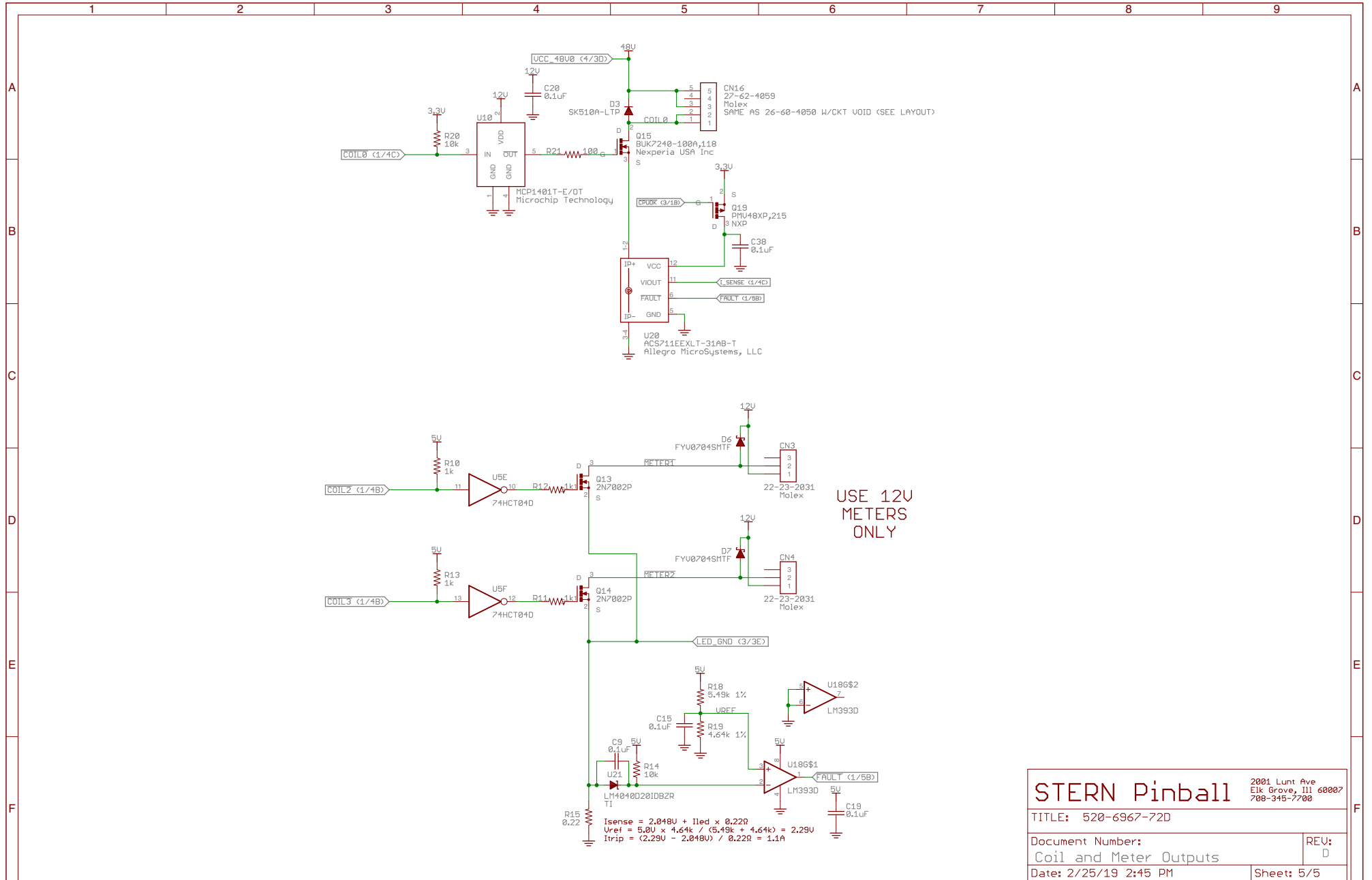


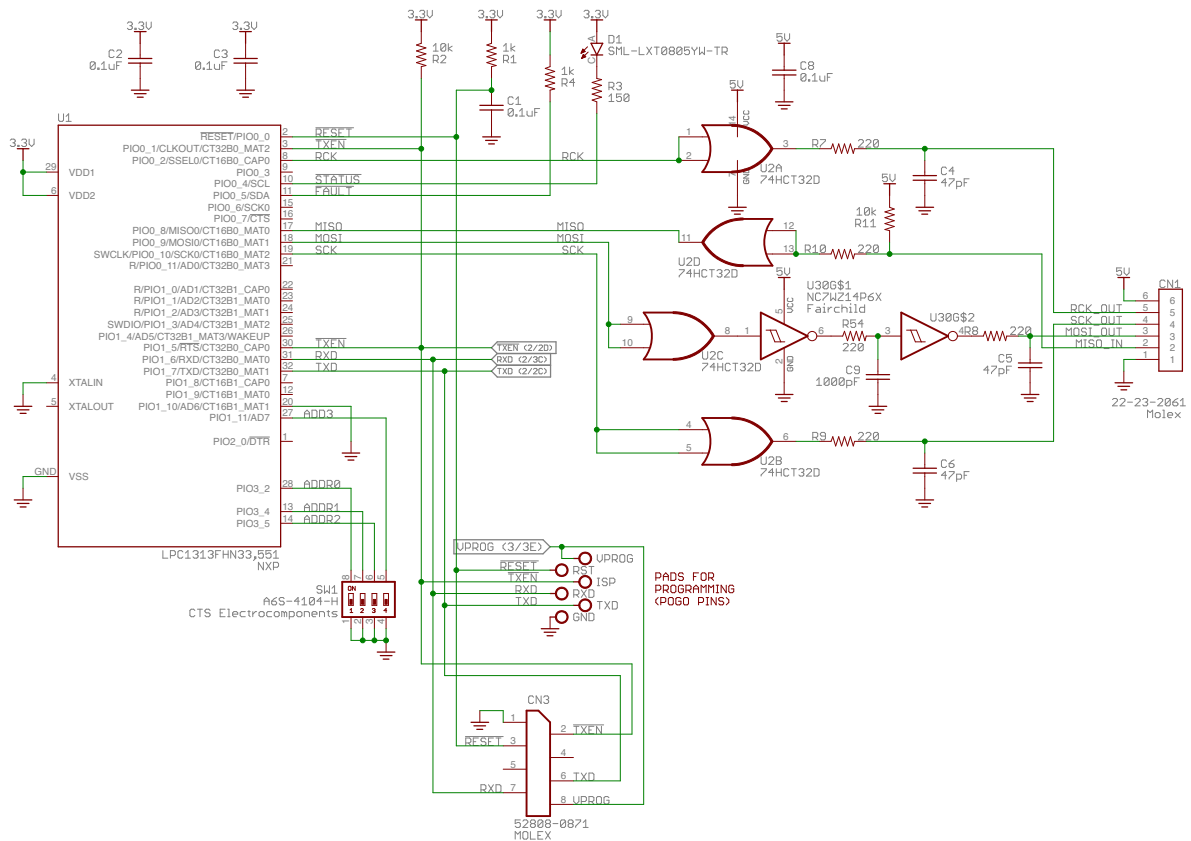
STERN Pinball 2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700			
		TITLE: 520-6967-72D	
Document Number:		REV:	
Communications		D	
Date: 2/25/19 2:45 PM		Sheet: 2/5	





STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
TITLE: 520-6967-72D			
Document Number: Power Supply			REV: D
Date: 2/25/19 2:45 PM			Sheet: 4/5





LED STATUS TABLE

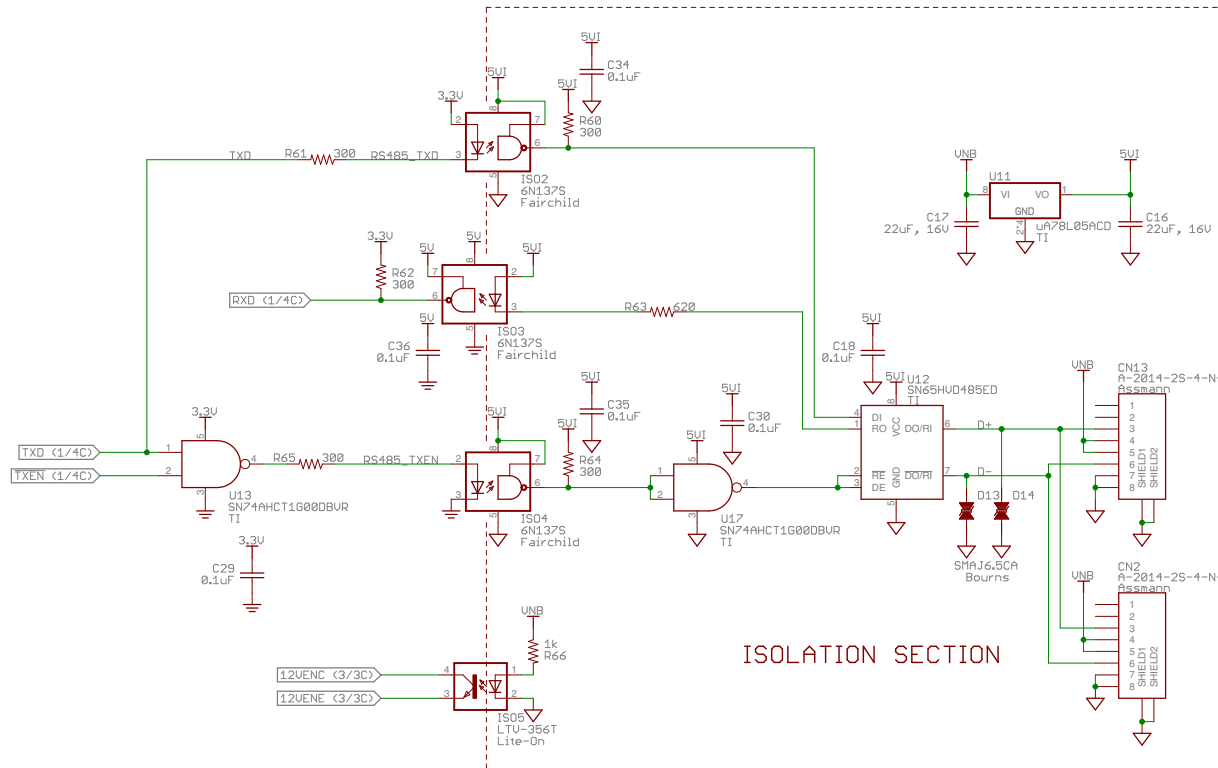
48V	5V	MCU status	DESCRIPTION
D19	D5	D1	
RED	RED	YELLOW	
OFF	OFF	OFF	48V not present: check that system is connected and powered
ON	OFF	OFF	48V present, no 5V: node bus is powered off by CPU, node bus cable is unplugged, or 5V supply is overloaded (shorted) or damaged
ON	ON	OFF	48V present, 5V present, processor not running: check 3.3V supply
ON	ON	10Hz 50%	power okay, processor in boot node waiting for runtime update: check node cable, ensure other nodes are communicating, check communication interface
ON	ON	1Hz 90%	power okay, processor in runtime mode but not receiving from CPU: check node cable, ensure other nodes are communicating, check communication interface
ON	ON	flickering	power okay, processor communicating and operating correctly

STERN Pinball 2001 Lunt Ave
Elk Grove, Ill 60007
708-345-7700

TITLE: 520-6976-72A

Document Number: _____ REV: _____

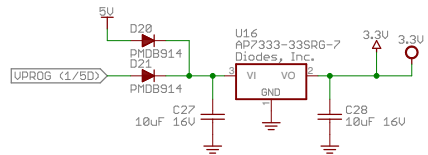
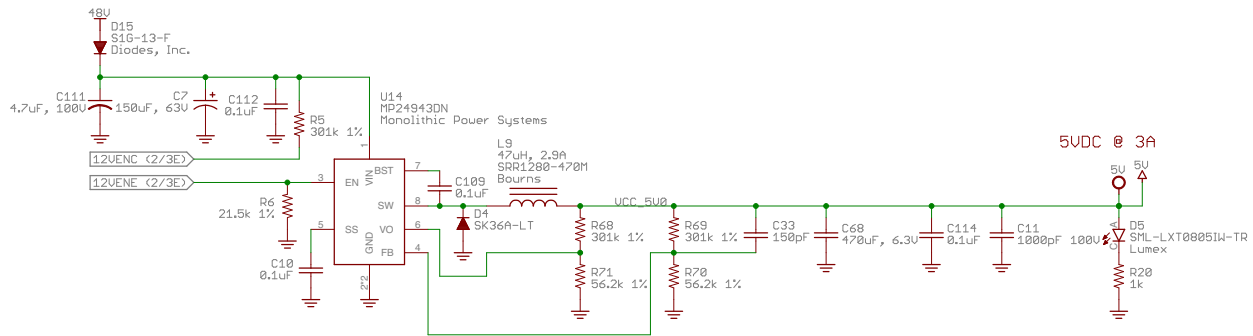
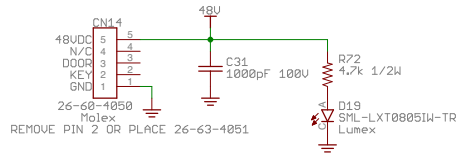
Date: 2/25/19 2:58 PM Sheet: 1/3



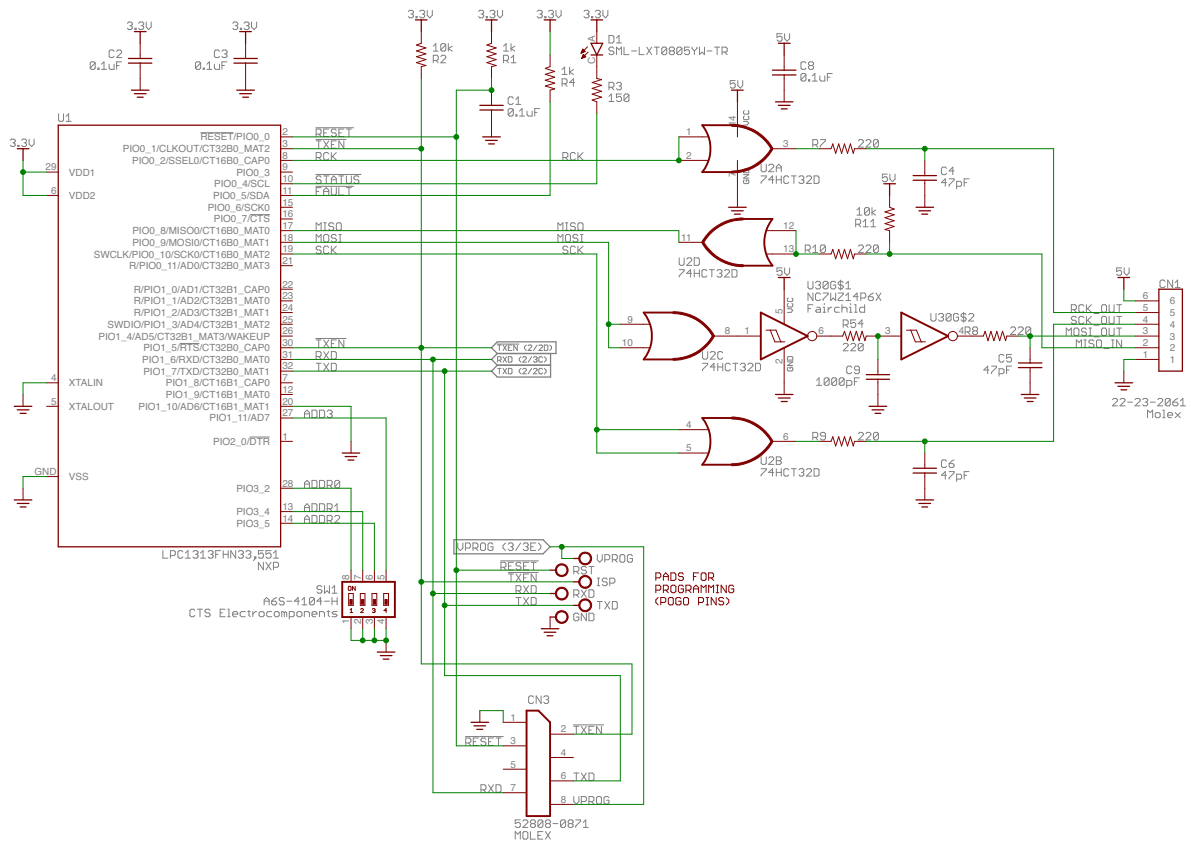
ISOLATION SECTION

$U_{I(max)} = 1.8U$, $I_{f(con)X(max)} = 5.0mA$
 $(3.3V - 1.8U) / 5.0mA = 300$
 $(5.0V - 1.8U) / 5.0mA = 640$

STERN Pinball TITLE: 520-6976-72A		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
		Document Number: Communication	REV:
Date: 2/25/19 2:58 PM		Sheet: 2/3	



STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-6976-72A		
Document Number:	REV:	
Power Supply		
Date: 2/25/19 2:58 PM	Sheet: 3/3	



LED STATUS TABLE

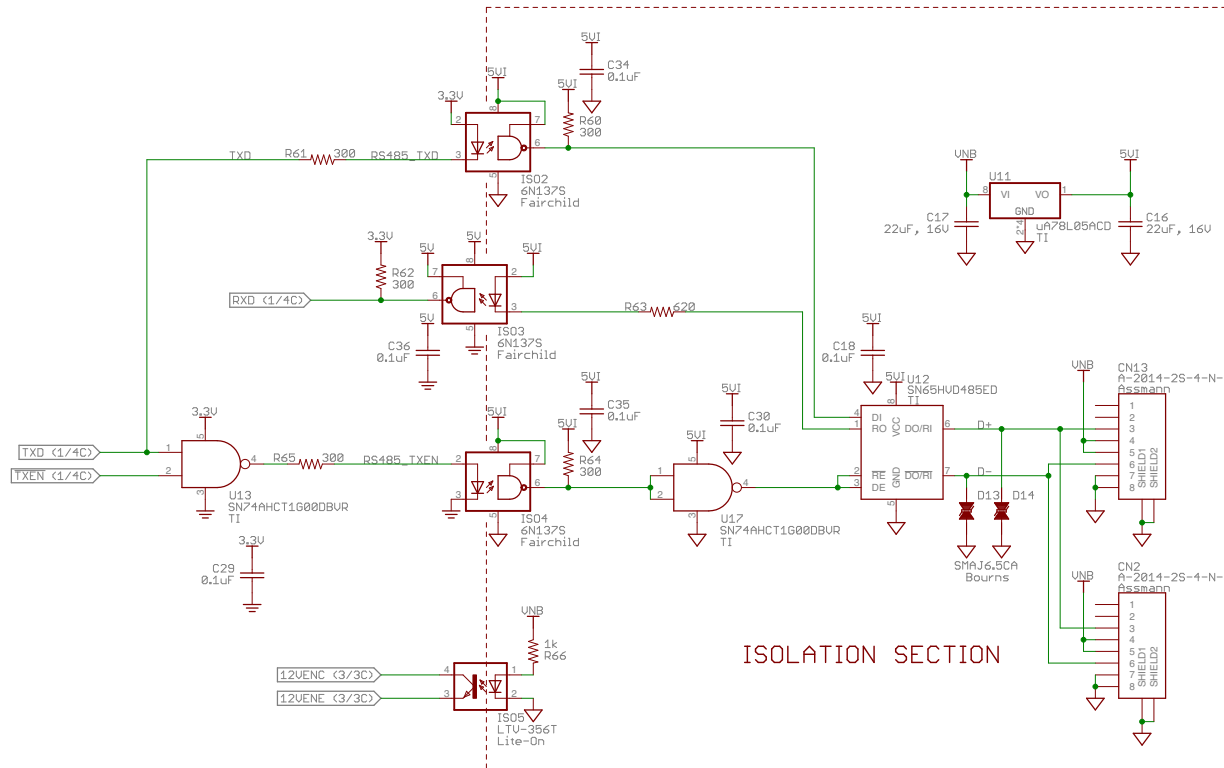
48V	5V	MCU status	DESCRIPTION
D19	D5	D1	
RED	RED	YELLOW	
OFF	OFF	OFF	48V not present: check that system is connected and powered
ON	OFF	OFF	48V present, no 5V: node bus is powered off by CPU, node bus cable is unplugged, or 5V supply is overloaded (shorted) or damaged
ON	ON	OFF	48V present, 5V present, processor not running: check 3.3V supply
ON	ON	10Hz 50%	power okay, processor in boot node waiting for runtime update: check node cable, ensure other nodes are communicating, check communication interface
ON	ON	1Hz 90%	power okay, processor in runtime mode but not receiving from CPU: check node cable, ensure other nodes are communicating, check communication interface
ON	ON	flickering	power okay, processor communicating and operating correctly

STERN Pinball 2001 Lunt Ave
Elk Grove, Ill 60007
708-345-7700

TITLE: 520-6976-72A

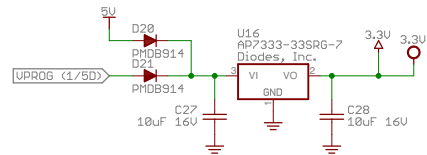
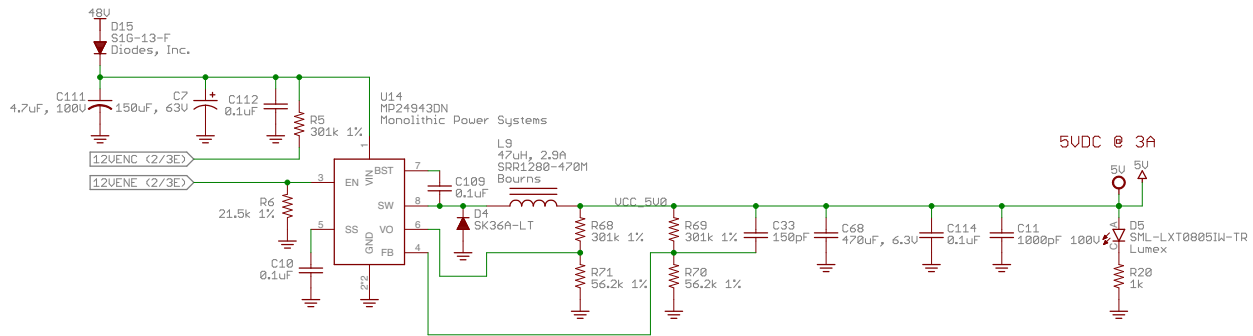
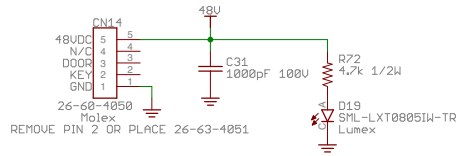
Document Number: _____ REV: _____

Date: 2/25/19 2:58 PM Sheet: 1/3

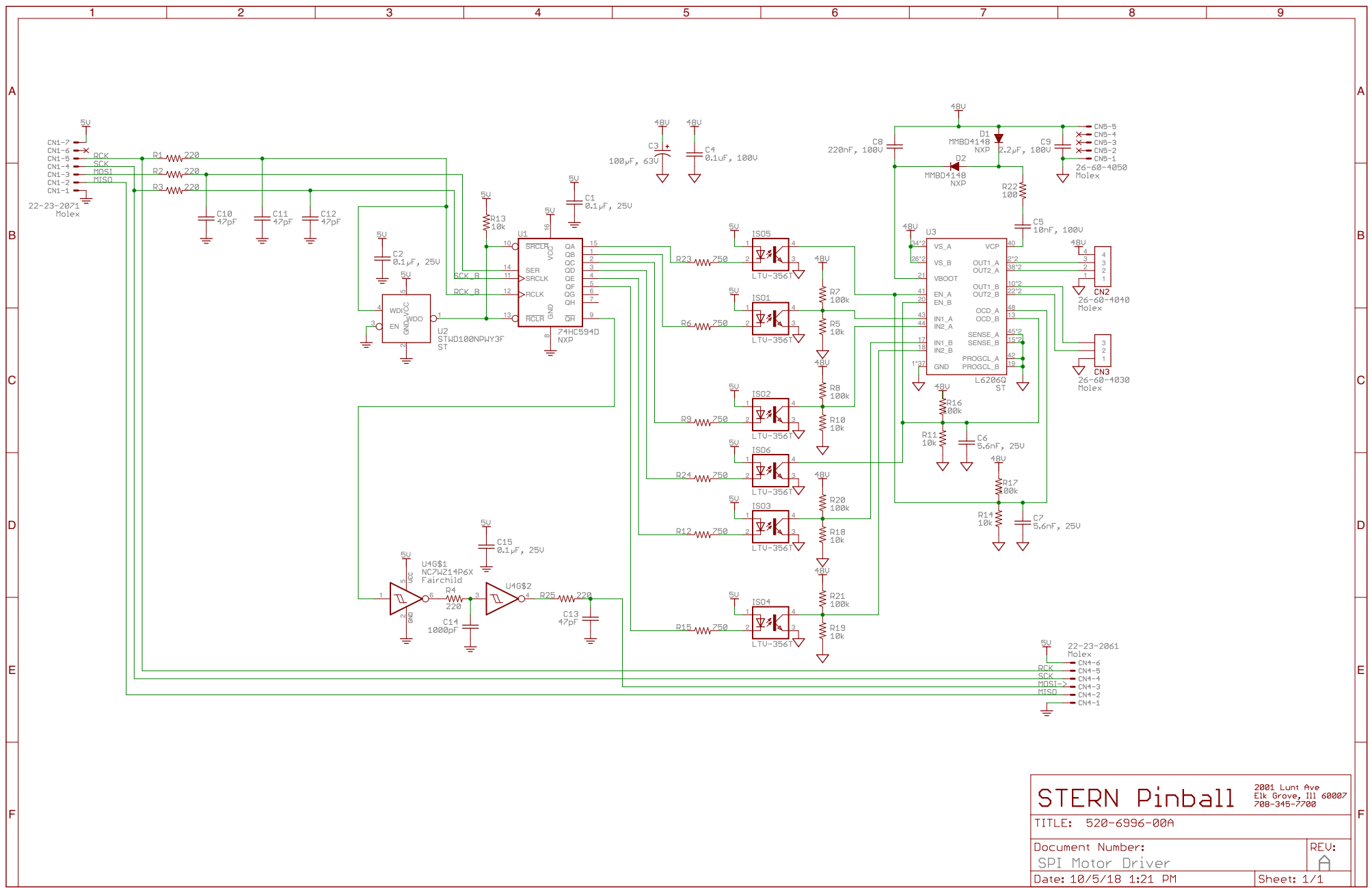


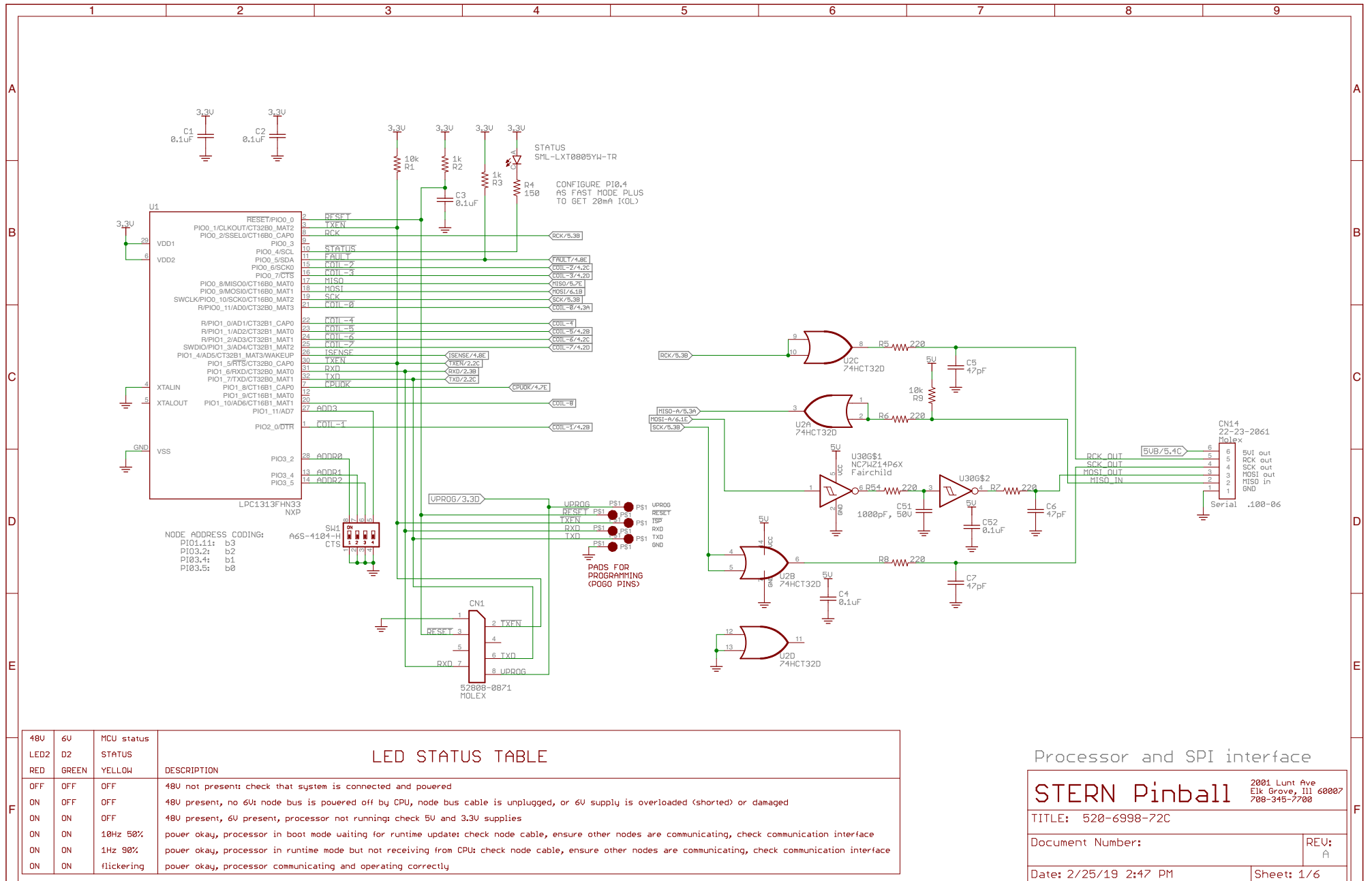
$U_{I(max)} = 1.8U$, $I_{f(con)}(max) = 5.0mA$
 $(3.3V - 1.8U) / 5.0mA = 300$
 $(5.0V - 1.8U) / 5.0mA = 640$

STERN Pinball TITLE: 520-6976-72A		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
		Document Number: Communication	REV:
Date: 2/25/19 2:58 PM		Sheet: 2/3	



STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-6976-72A		
Document Number:	REV:	
Power Supply		
Date: 2/25/19 2:58 PM	Sheet: 3/3	





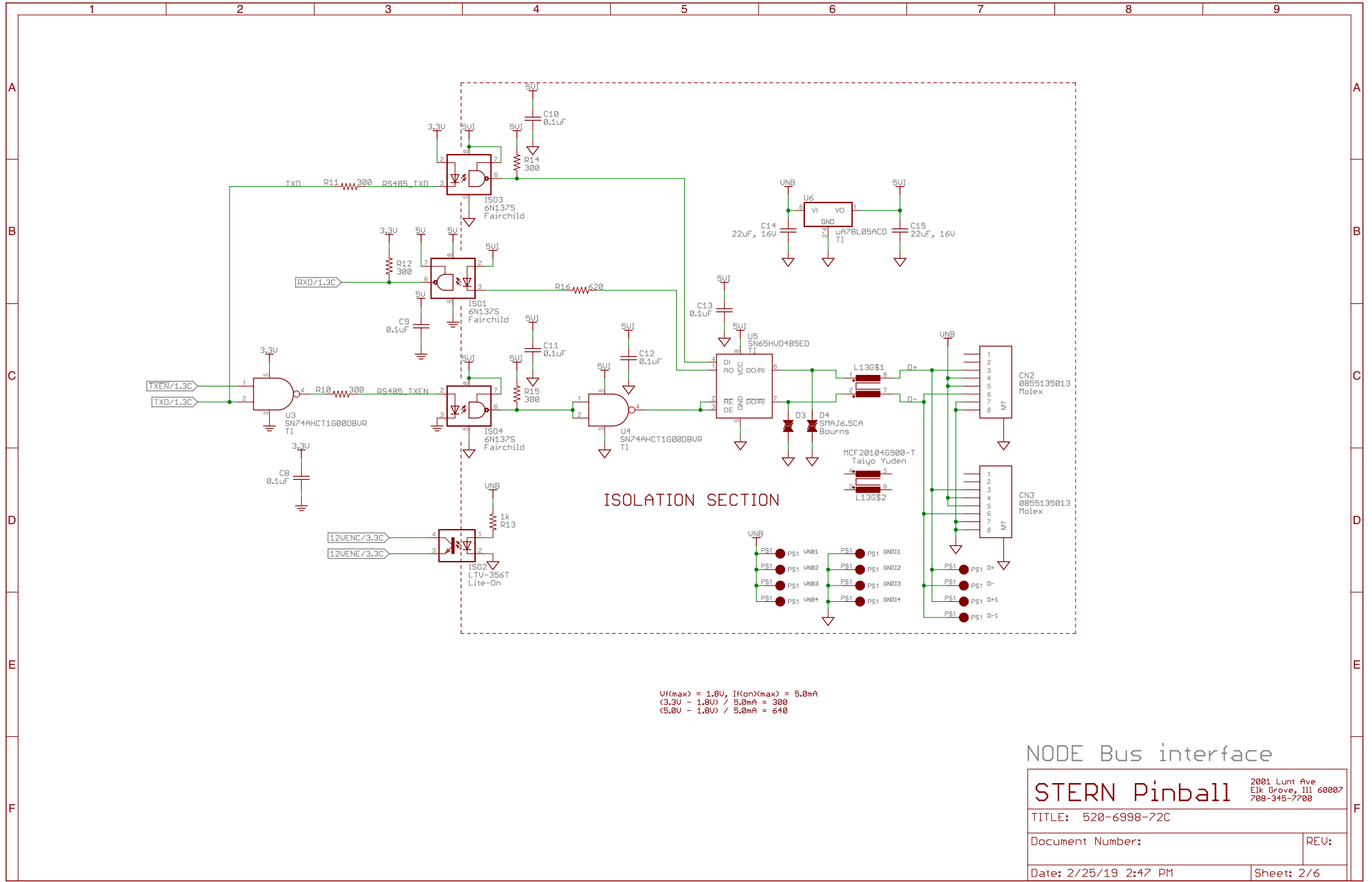
Processor and SPI interface

STERN Pinball 2001 Lunt Ave
Elk Grove, Ill 60007
708-345-7700

TITLE: 520-6998-72C

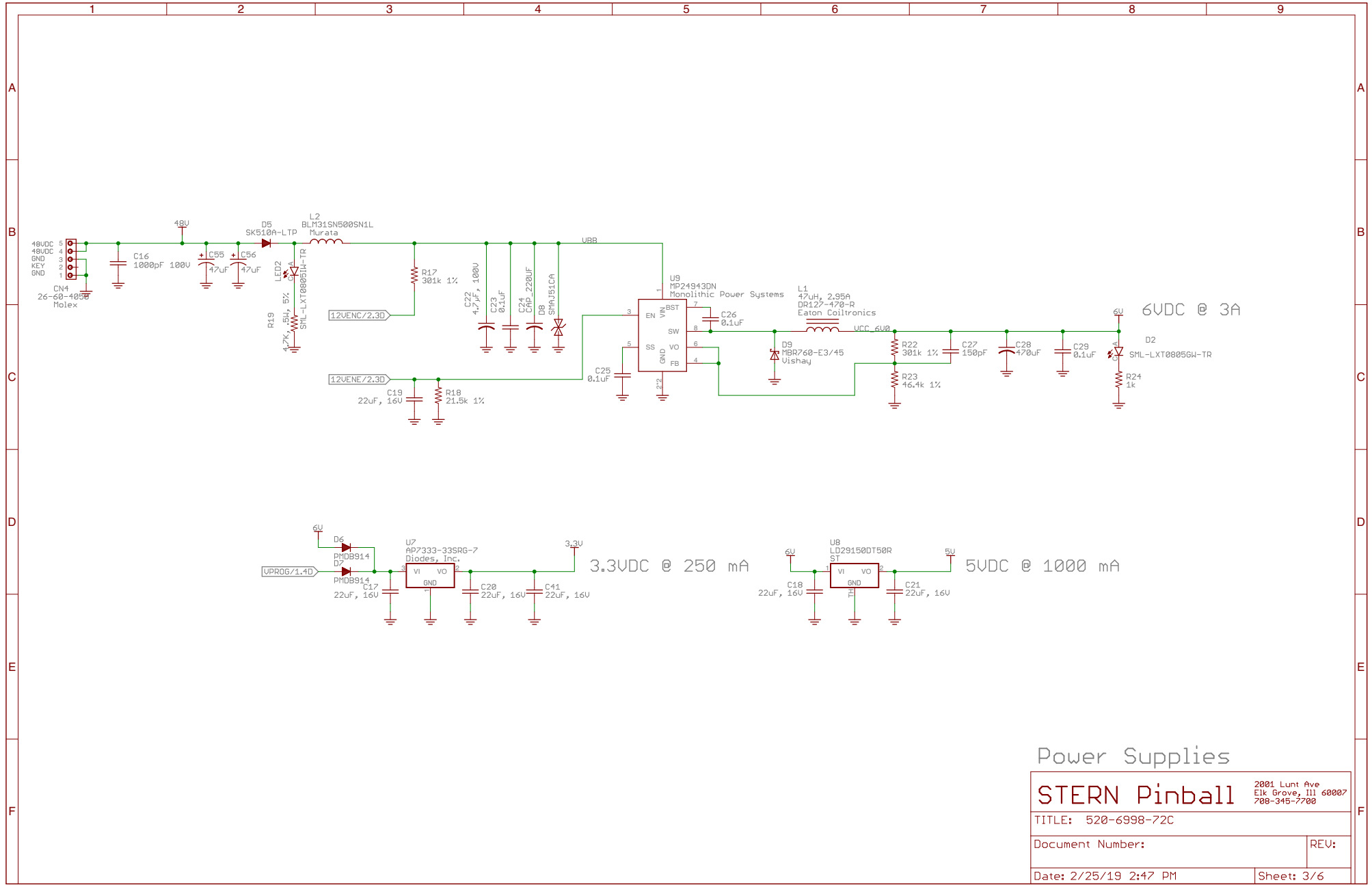
Document Number: REV: A

Date: 2/25/19 2:47 PM Sheet: 1/6



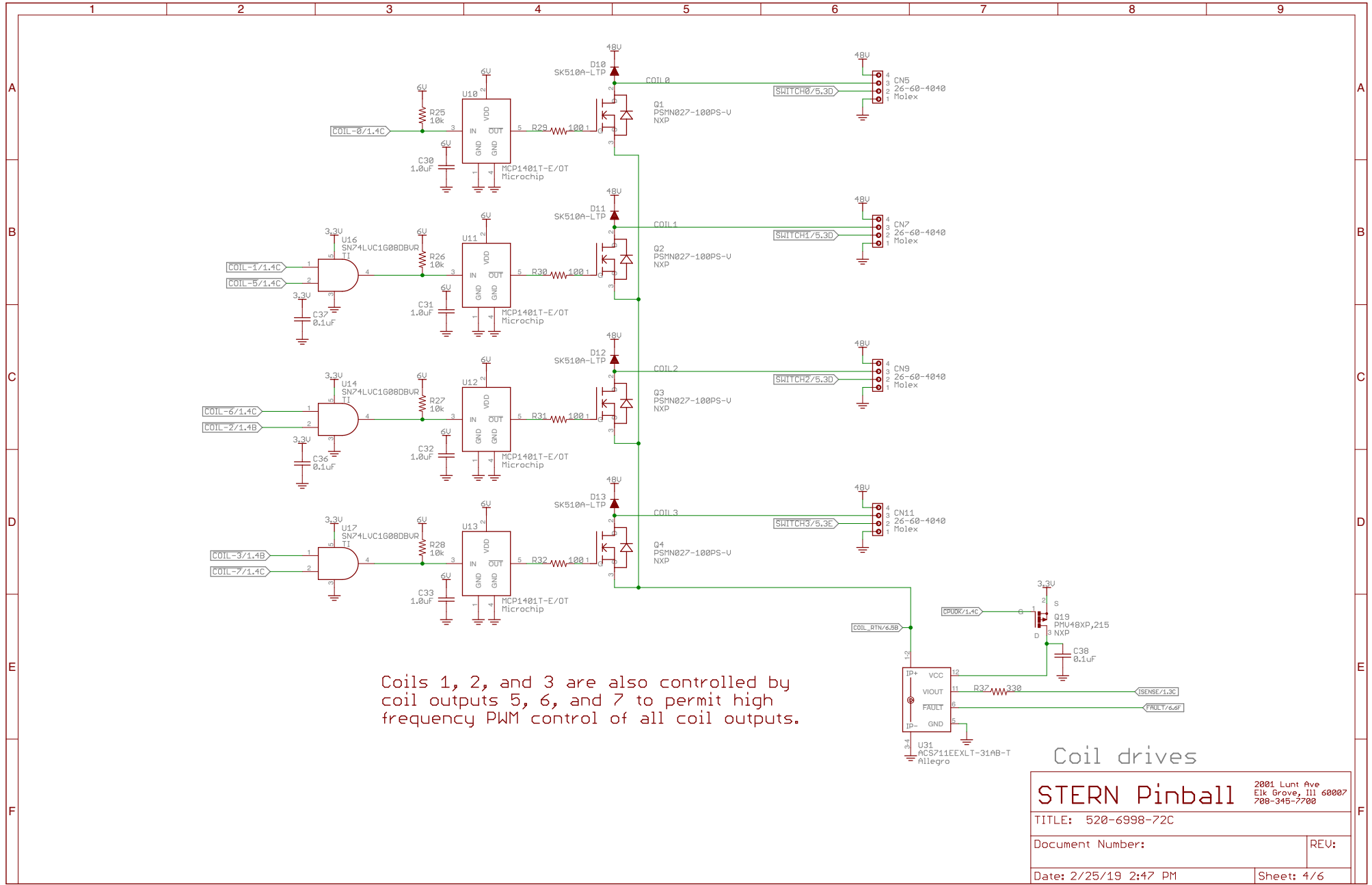
NODE Bus interface

STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
TITLE: 520-6998-72C			
Document Number:			REV:
Date: 2/25/19 2:47 PM			Sheet: 2/6



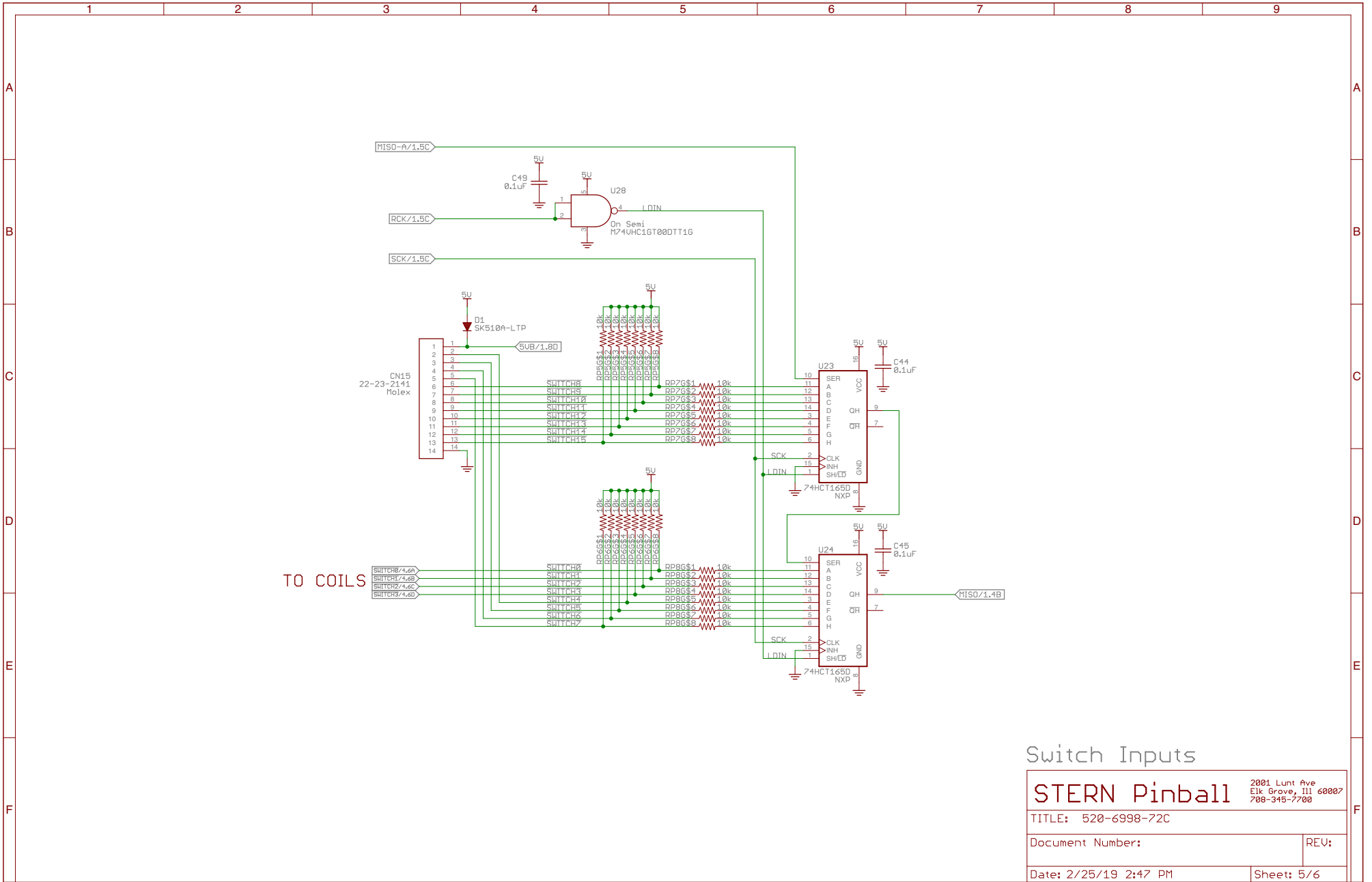
Power Supplies

STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-6998-72C		
Document Number:	REV:	
Date: 2/25/19 2:47 PM	Sheet: 3/6	



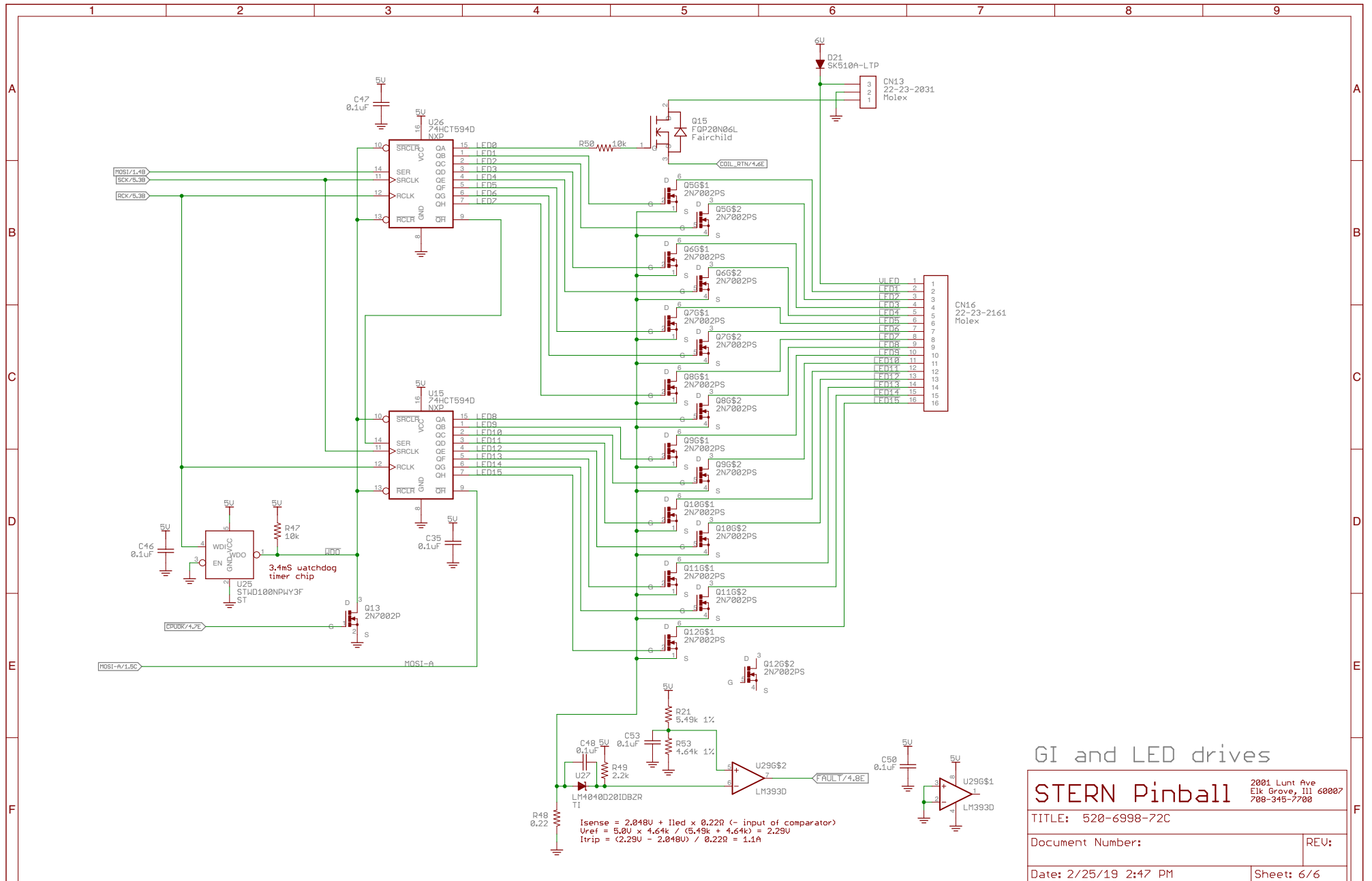
Coil drives

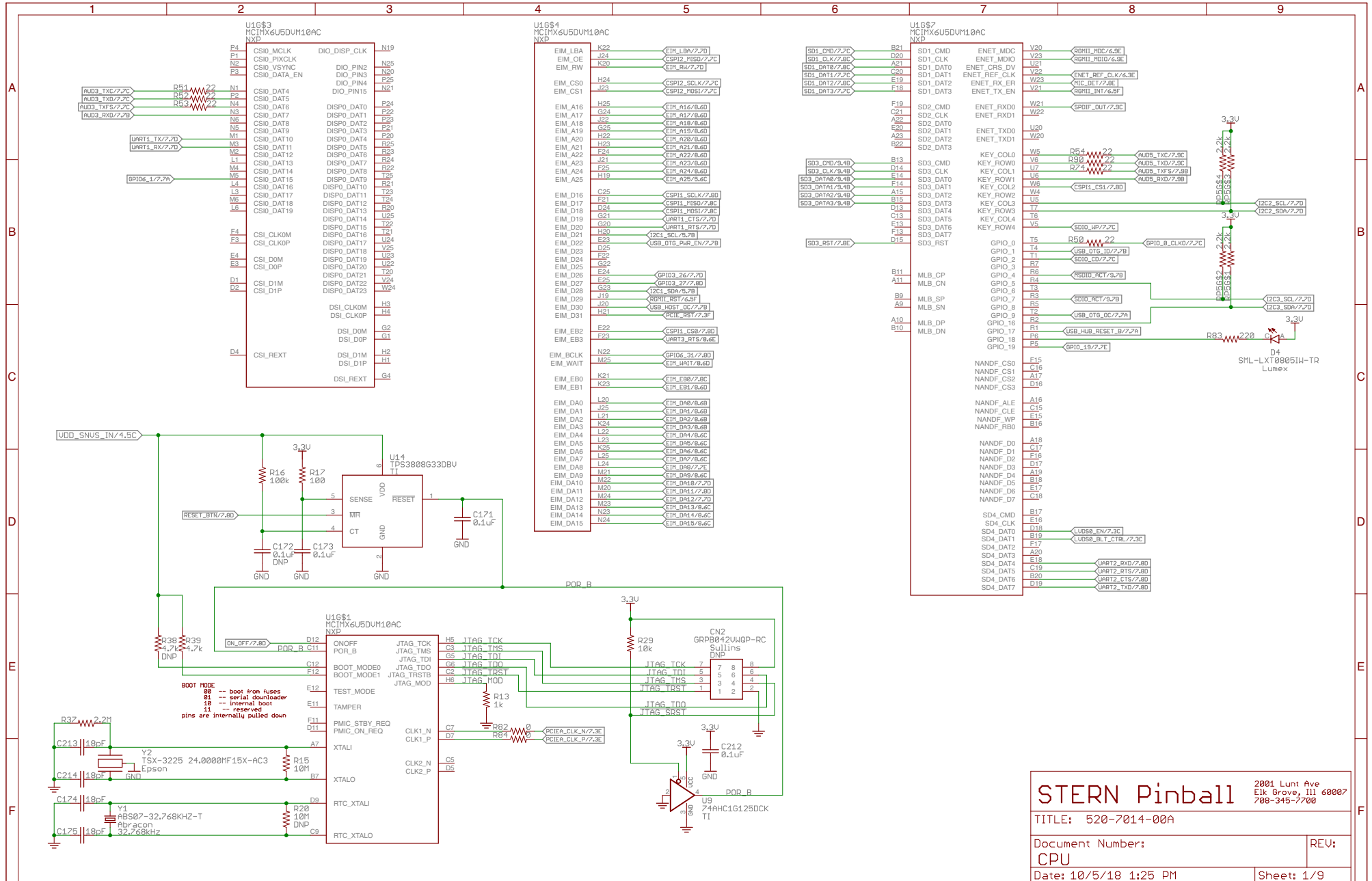
STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-6998-72C		
Document Number:		REV:
Date: 2/25/19 2:47 PM		Sheet: 4/6

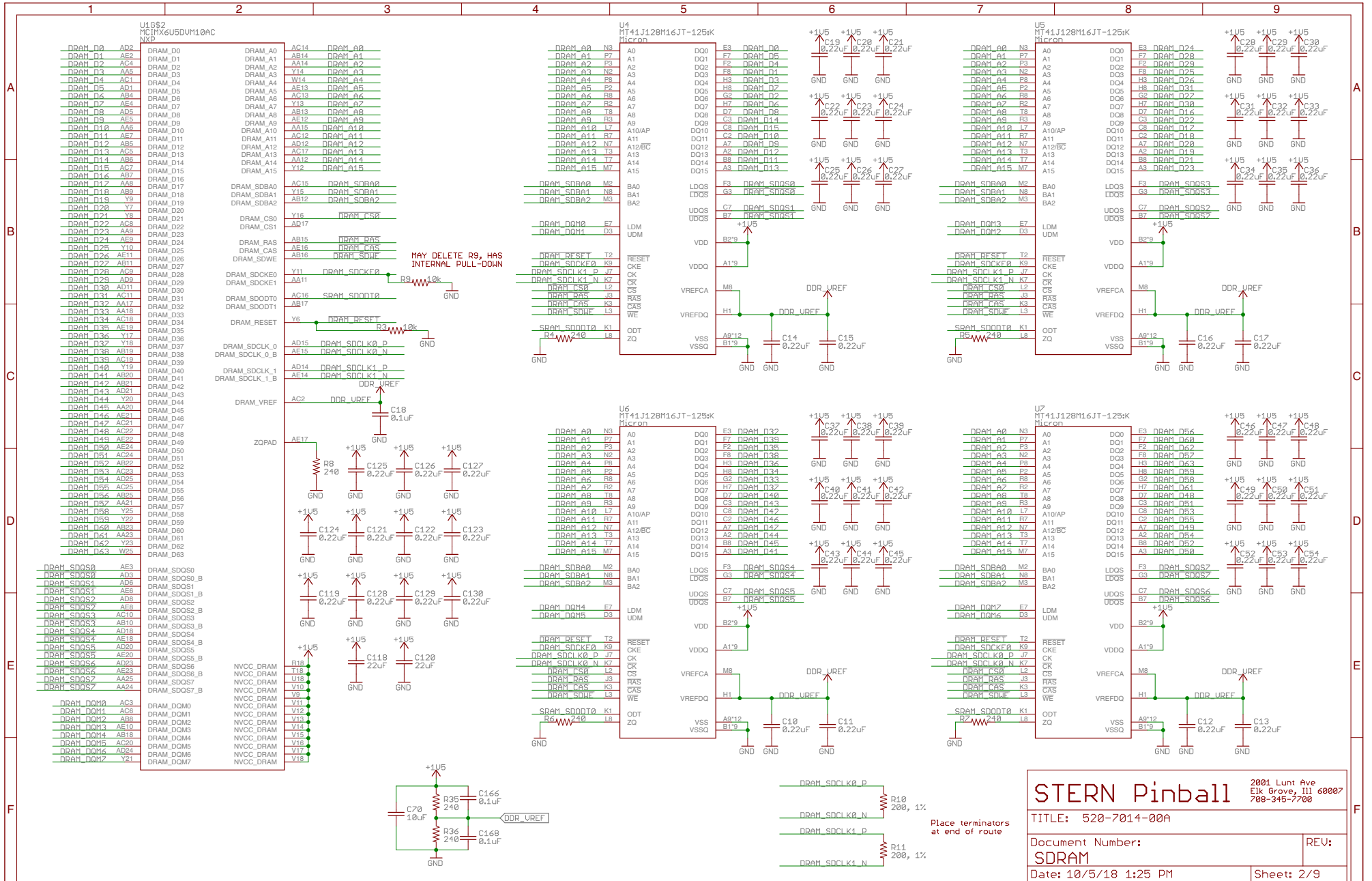


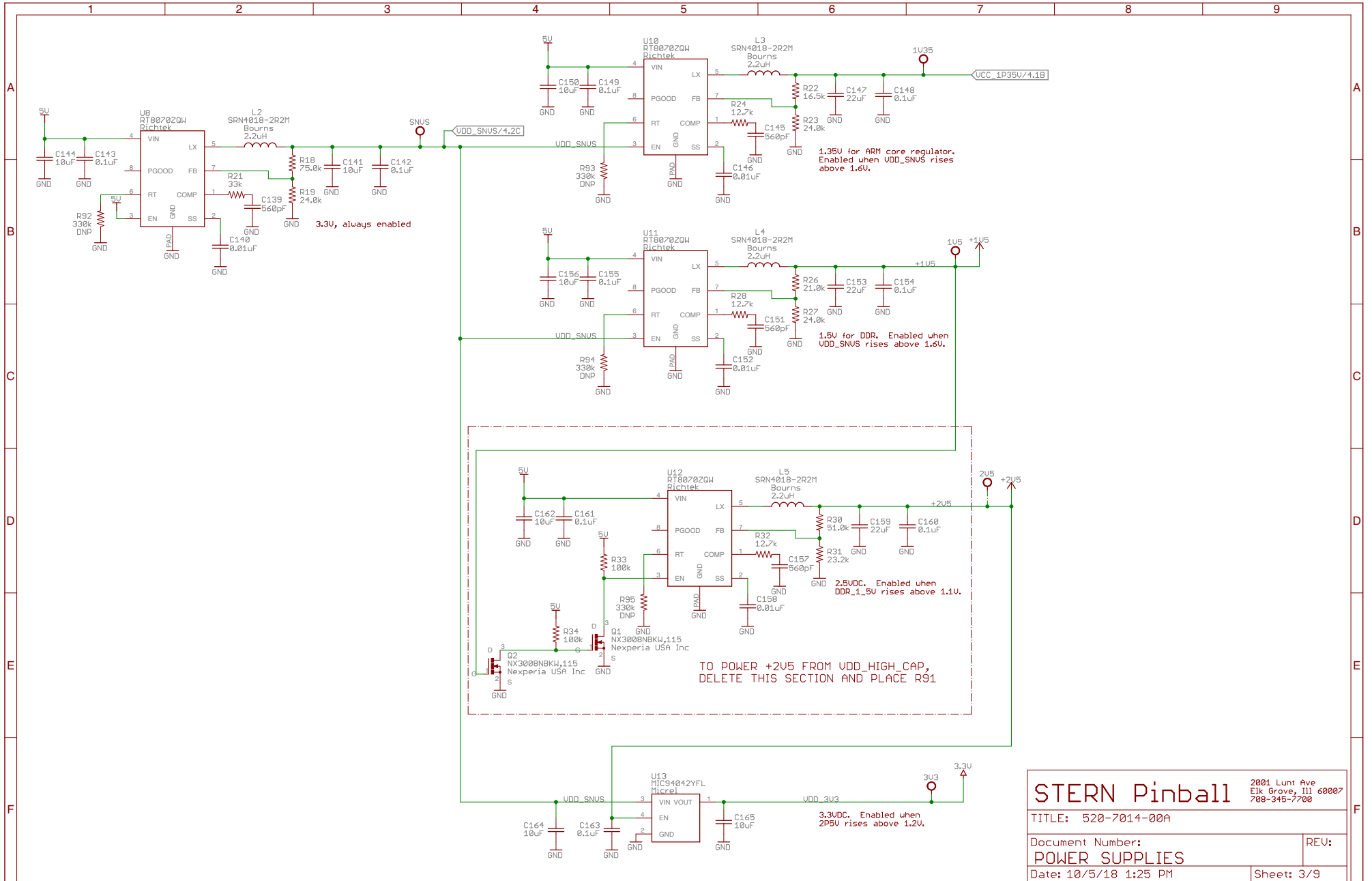
Switch Inputs

STERN Pinball 2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
TITLE: 520-6998-72C	
Document Number:	REV:
Date: 2/25/19 2:47 PM	Sheet: 5/6

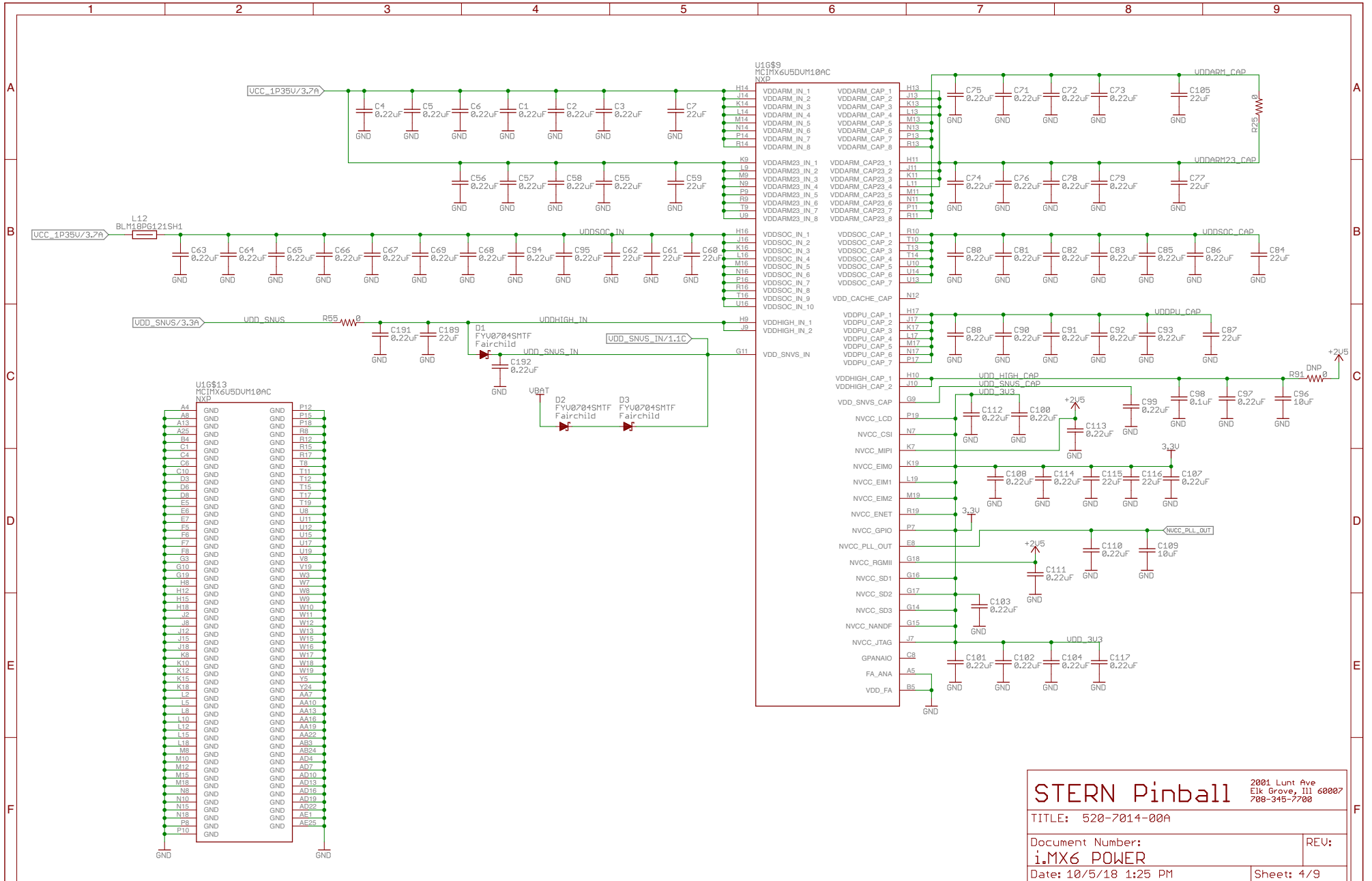








STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-7014-00A		
Document Number:	REV:	
POWER SUPPLIES		
Date: 10/5/18 1:25 PM	Sheet: 3/9	

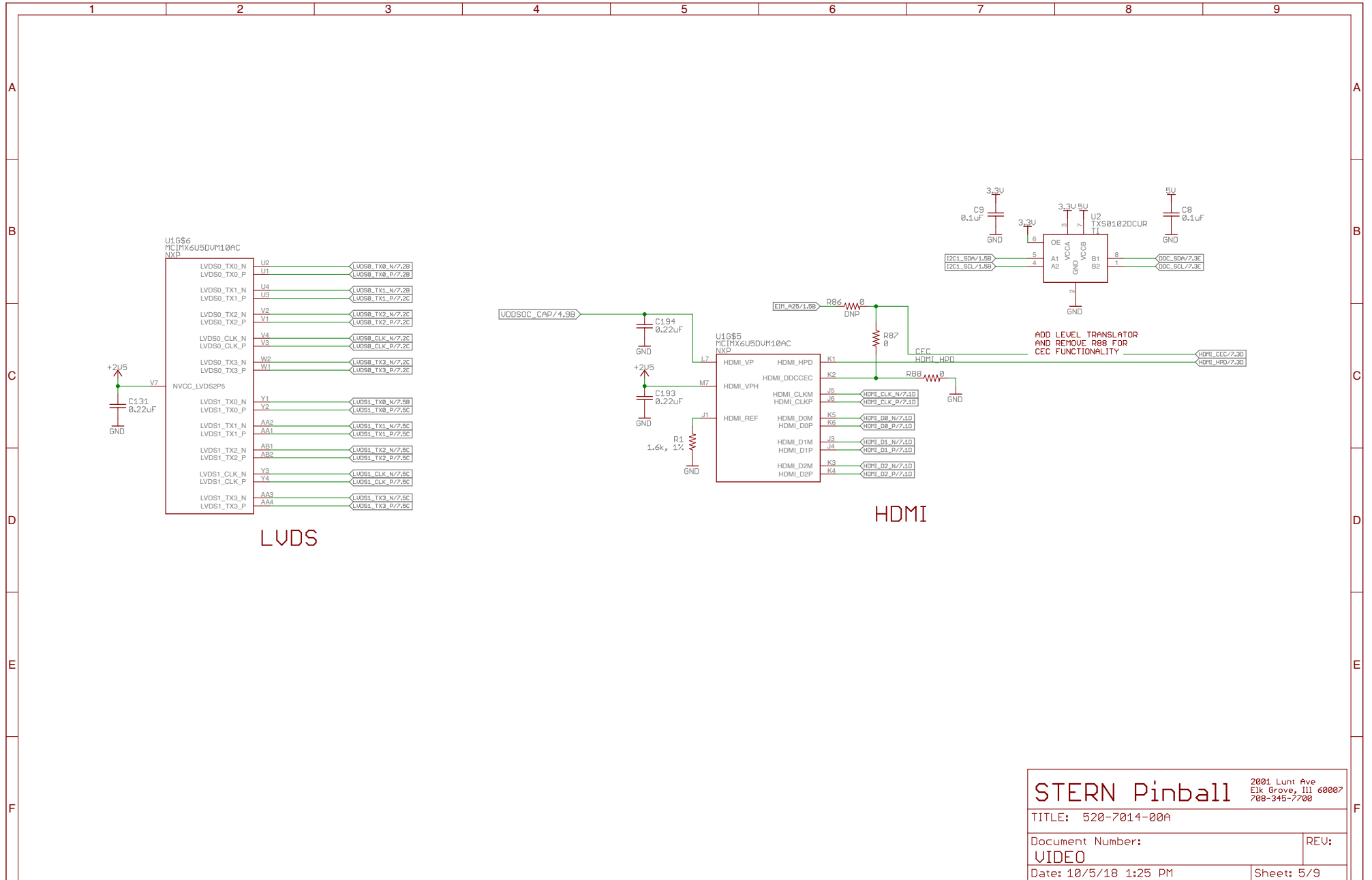


STERN Pinball 2001 Lunt Ave
Elk Grove, Ill 60007
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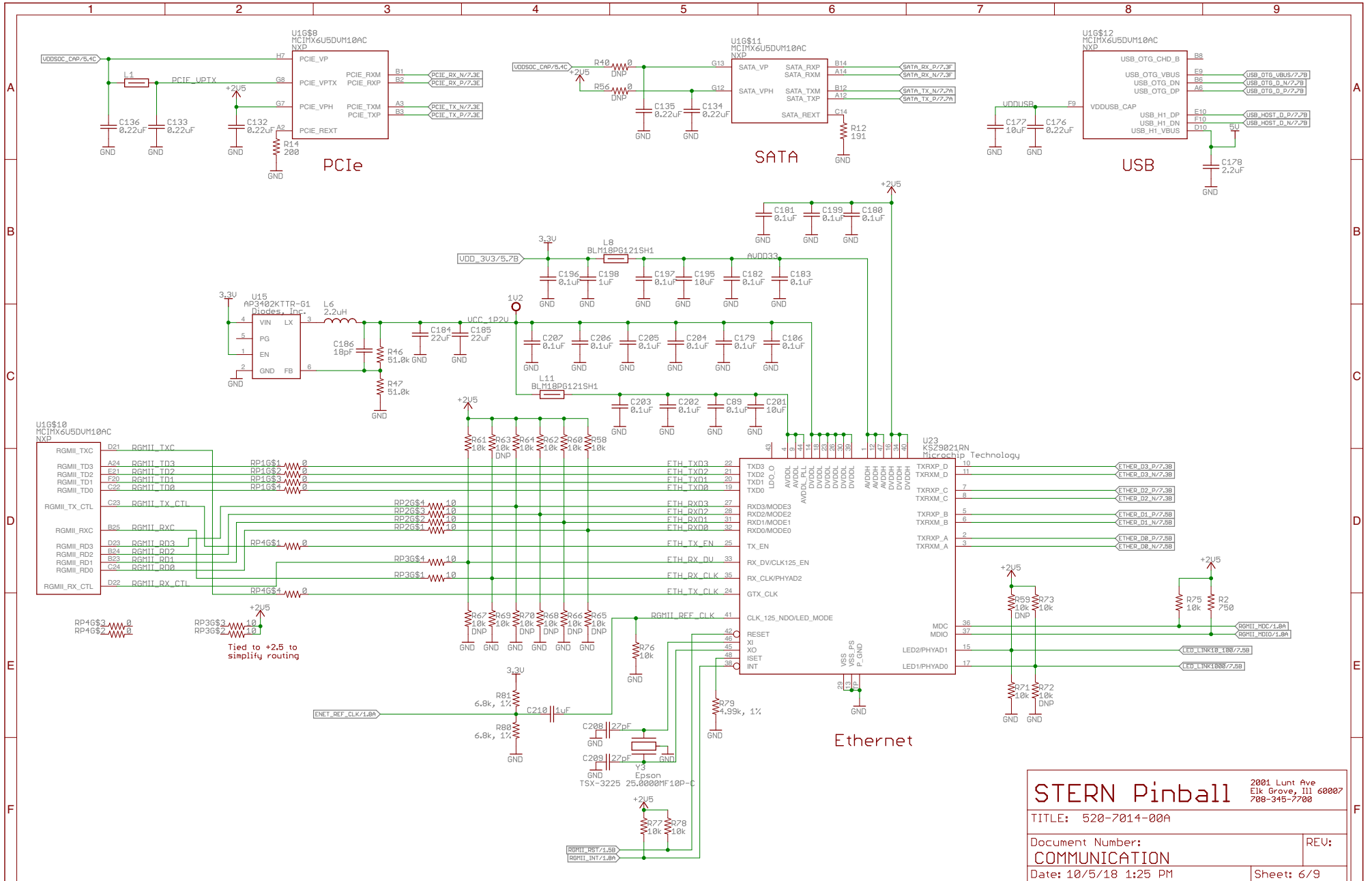
TITLE: 520-7014-00A

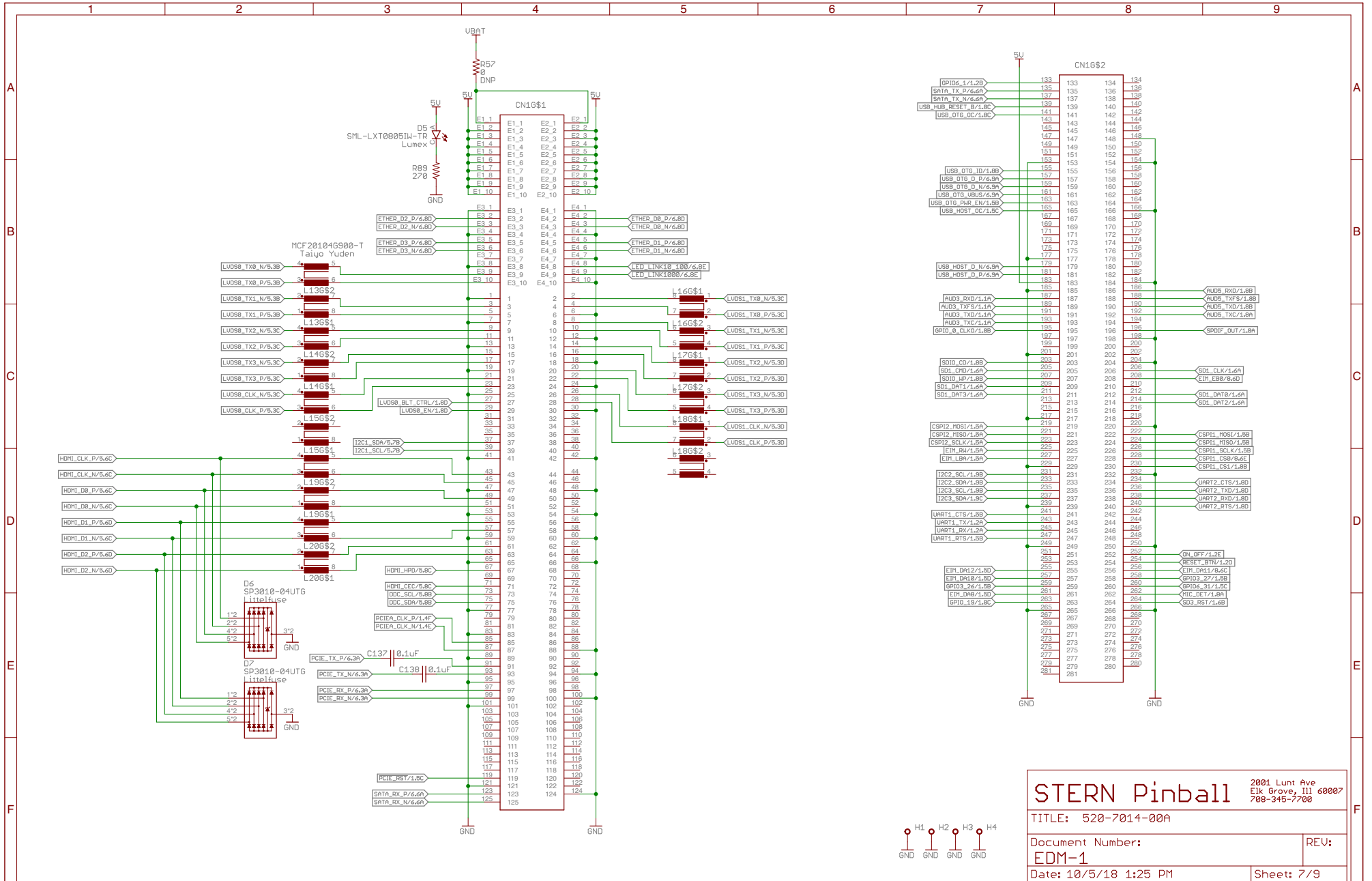
Document Number: _____ REV: _____

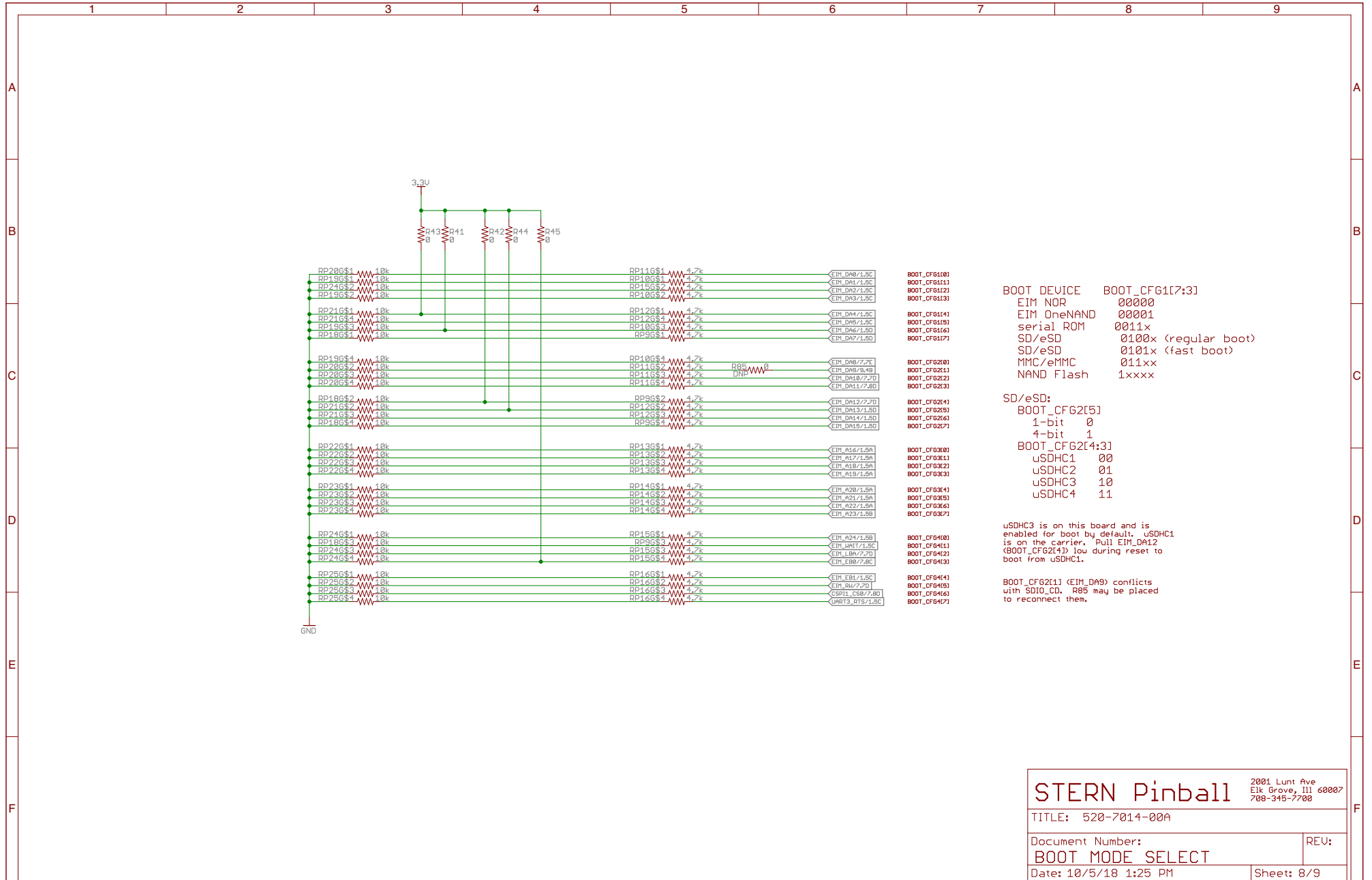
Date: 10/5/18 1:25 PM Sheet: 4/9



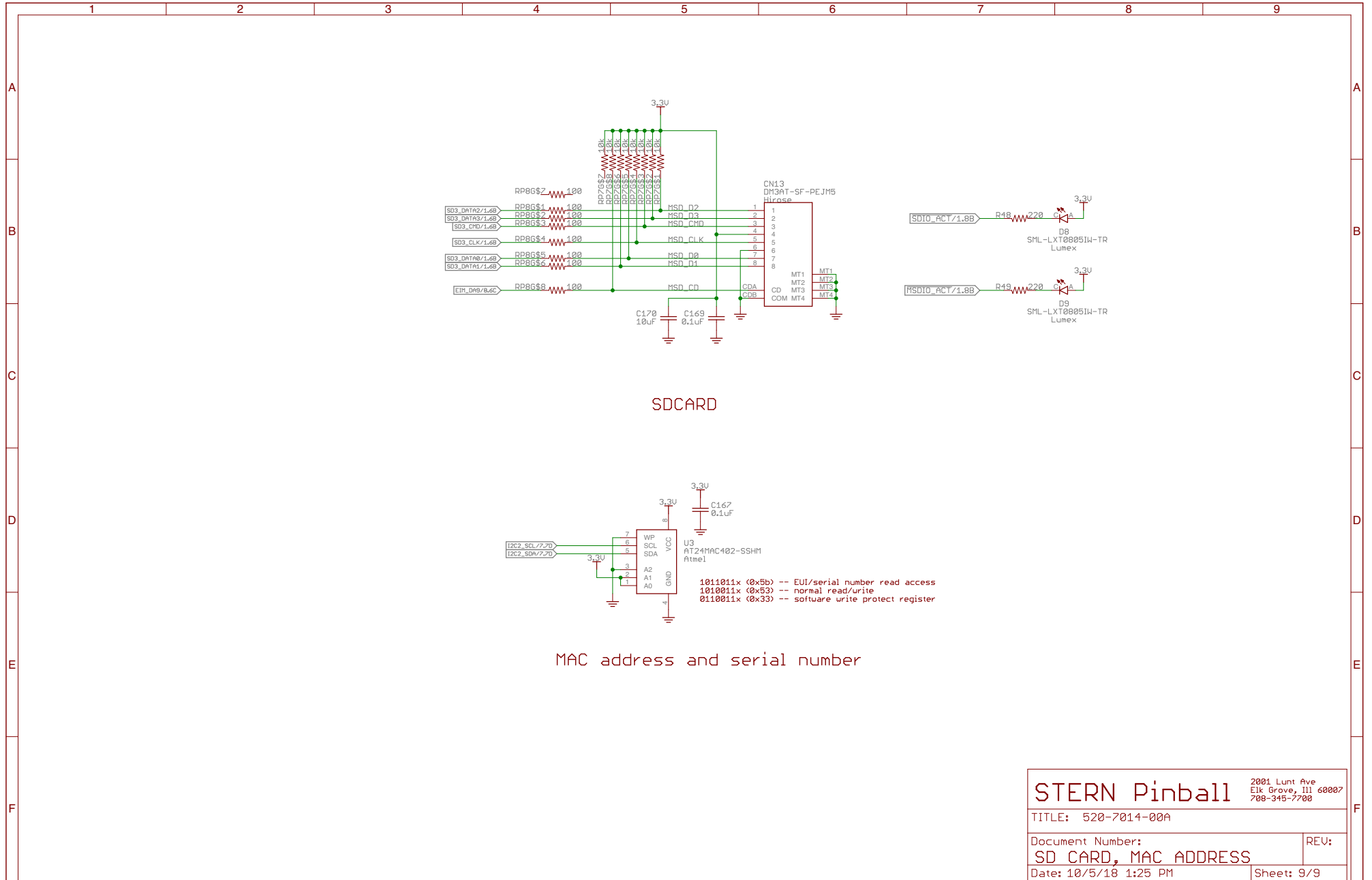
STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-7014-00A		
Document Number:		REV:
VIDEO		
Date: 10/5/18 1:25 PM		Sheet: 5/9



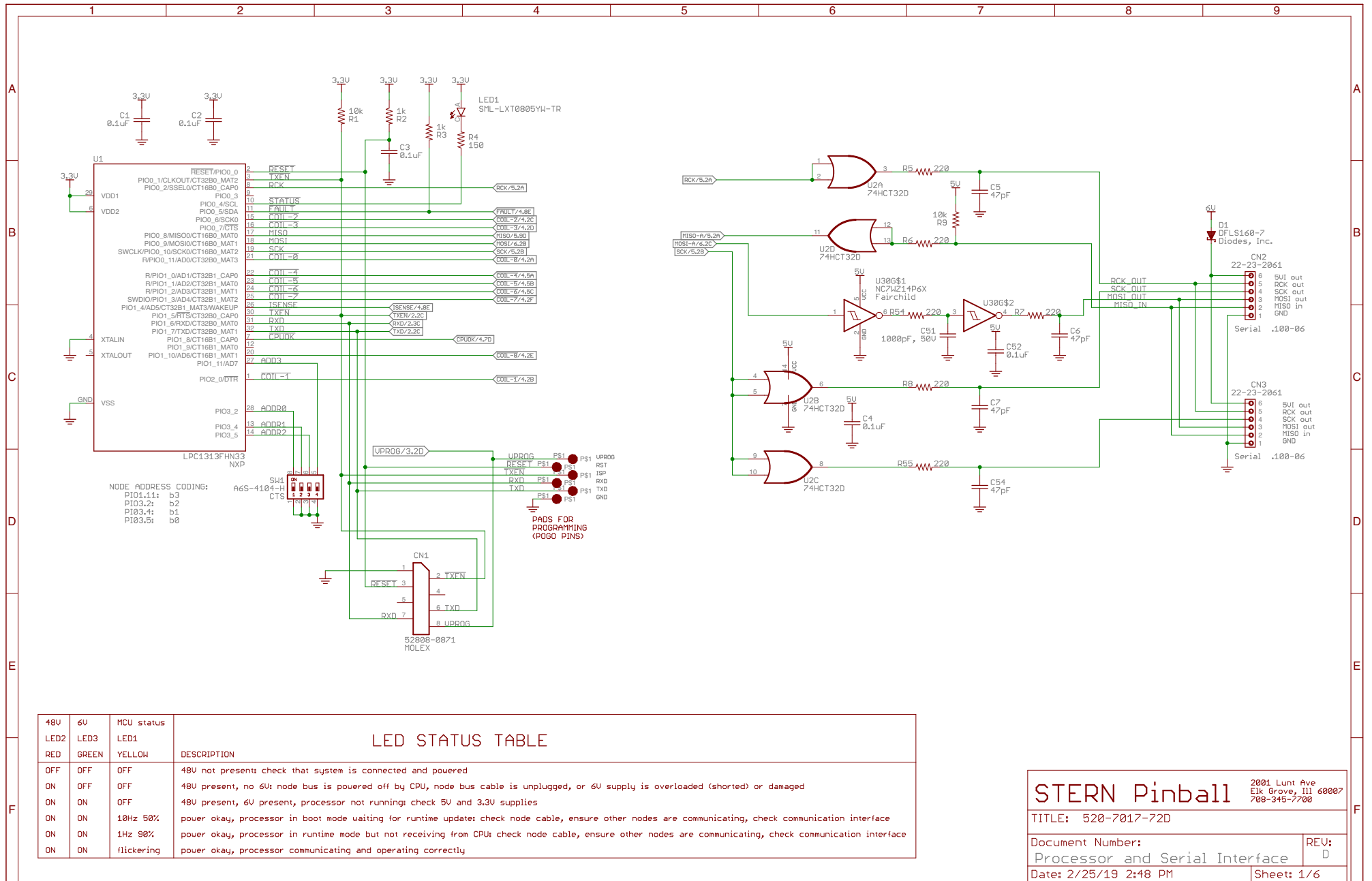


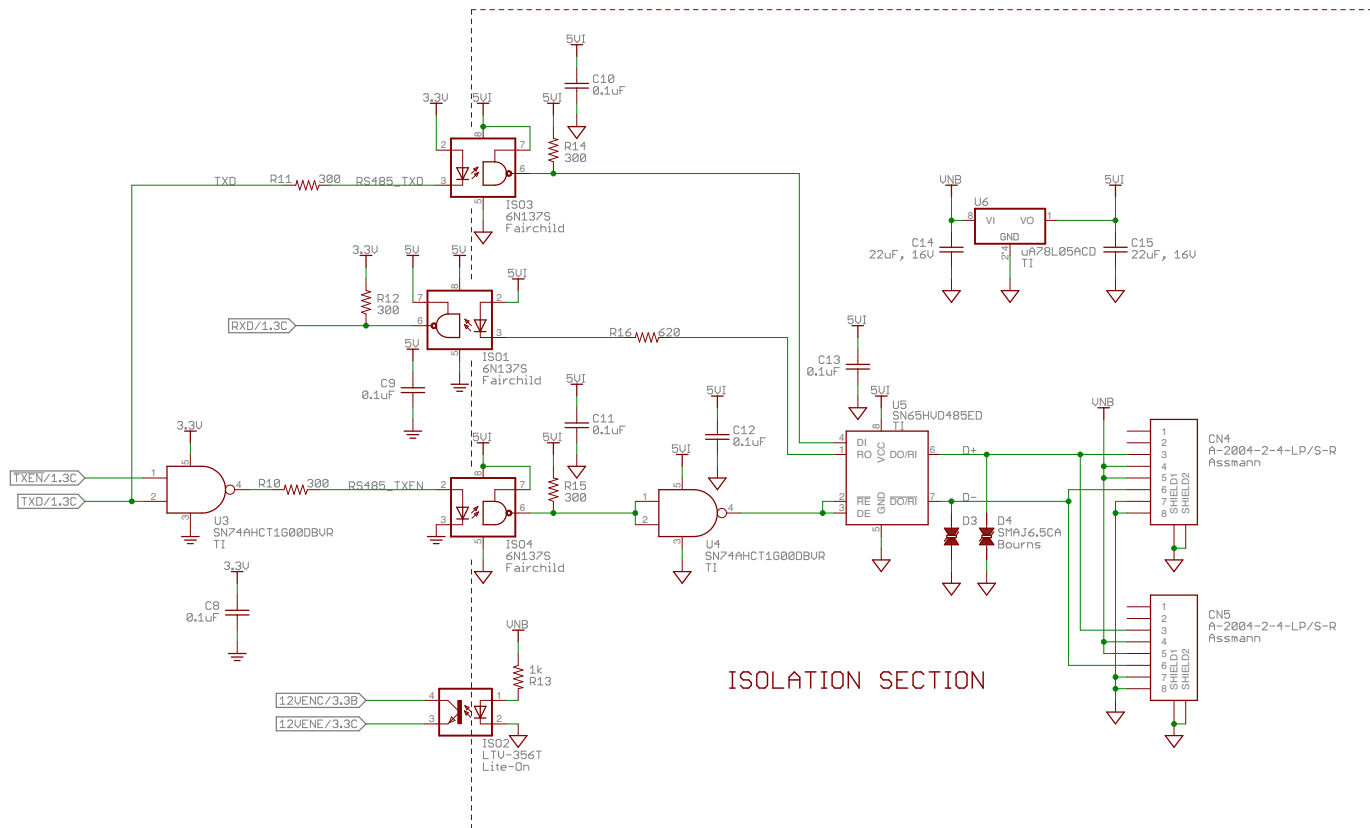


STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-7014-00A		
Document Number:	REV:	
BOOT MODE SELECT		
Date: 10/5/18 1:25 PM	Sheet: 8/9	



STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
		TITLE: 520-7014-00A	
Document Number:		REV:	
SD CARD, MAC ADDRESS			
Date: 10/5/18 1:25 PM		Sheet: 9/9	

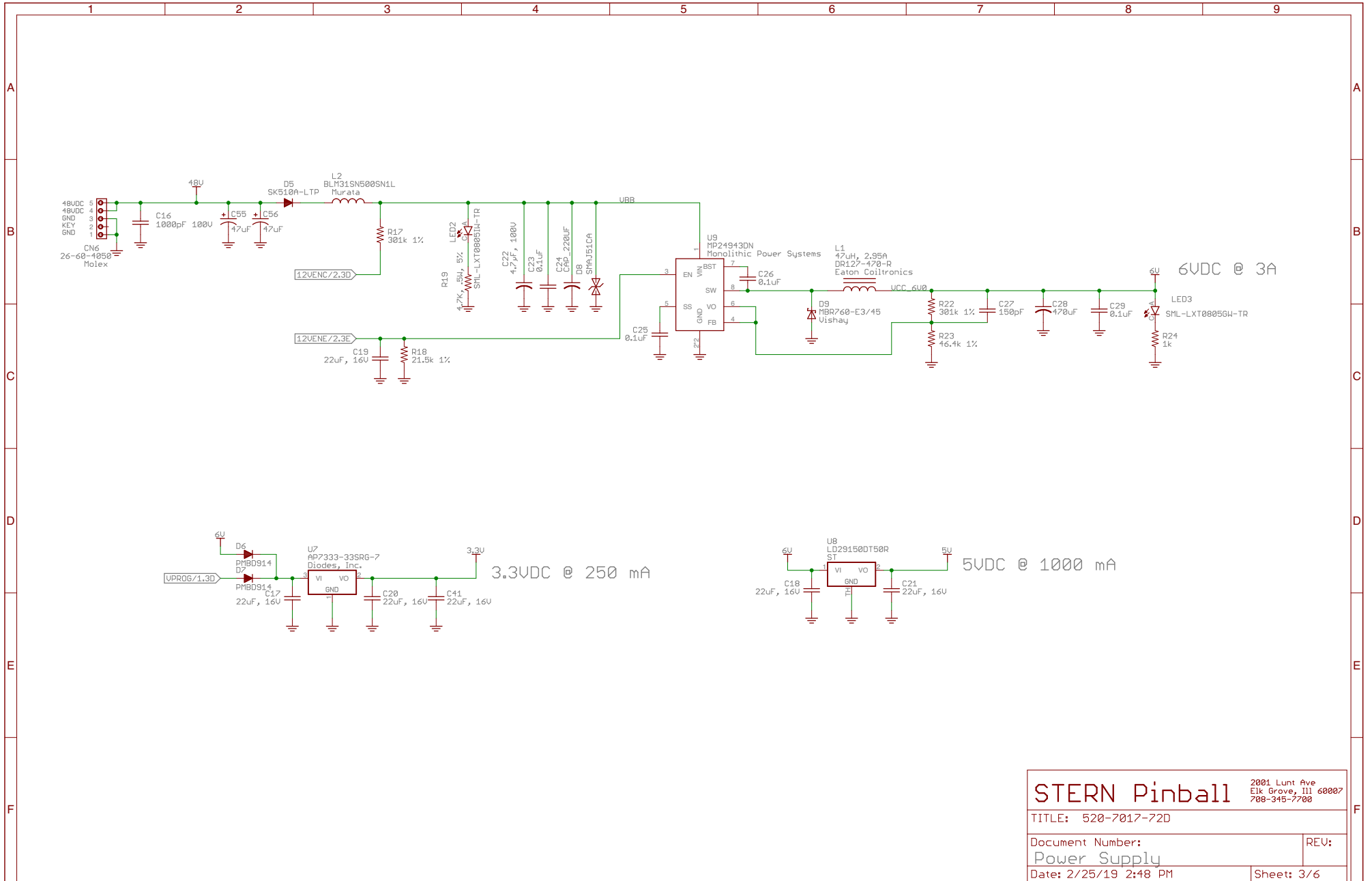




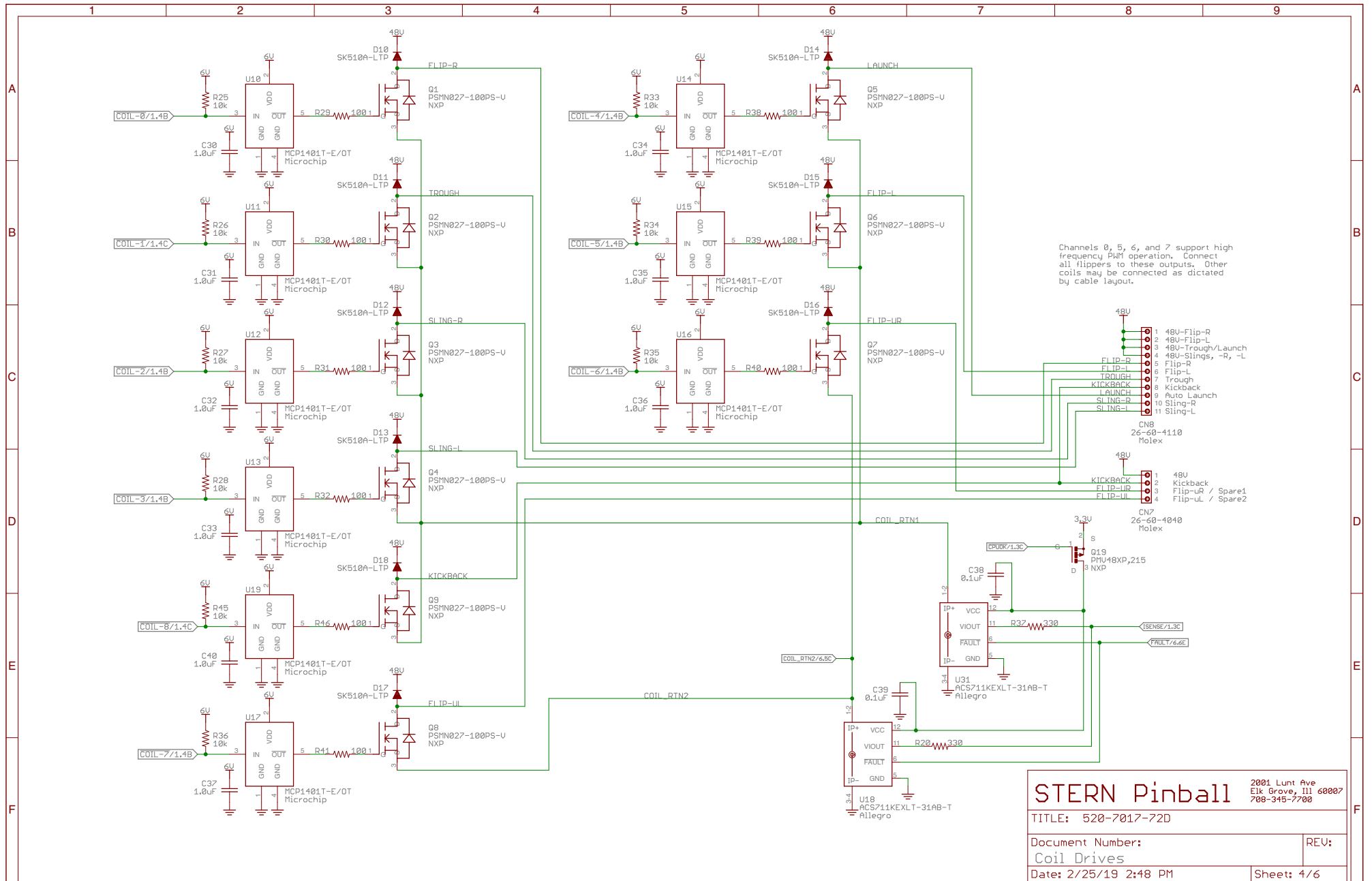
ISOLATION SECTION

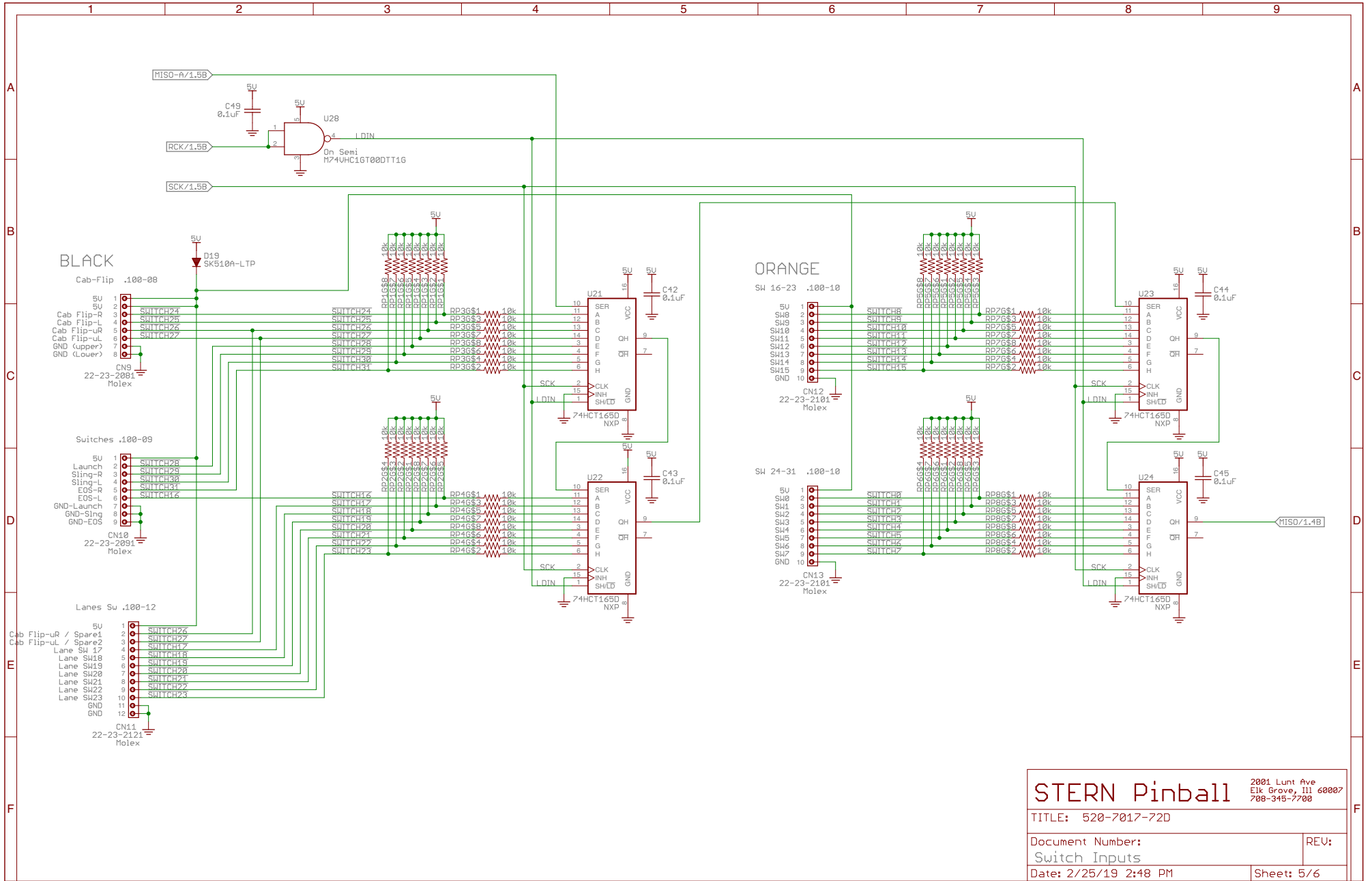
LED current limiting resistors:
 $V_f(\max) = 1.8V, I_f(\text{con}) = 5.0\text{mA}$
 $(3.3V - 1.8V) / 5.0\text{mA} = 300\Omega$
 $(5.0V - 1.8V) / 5.0\text{mA} = 640\Omega$ (use 620 Ω)

STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
TITLE: 520-7017-72D			
Document Number:			REV:
Communication			
Date: 2/25/19 2:48 PM			Sheet: 2/6

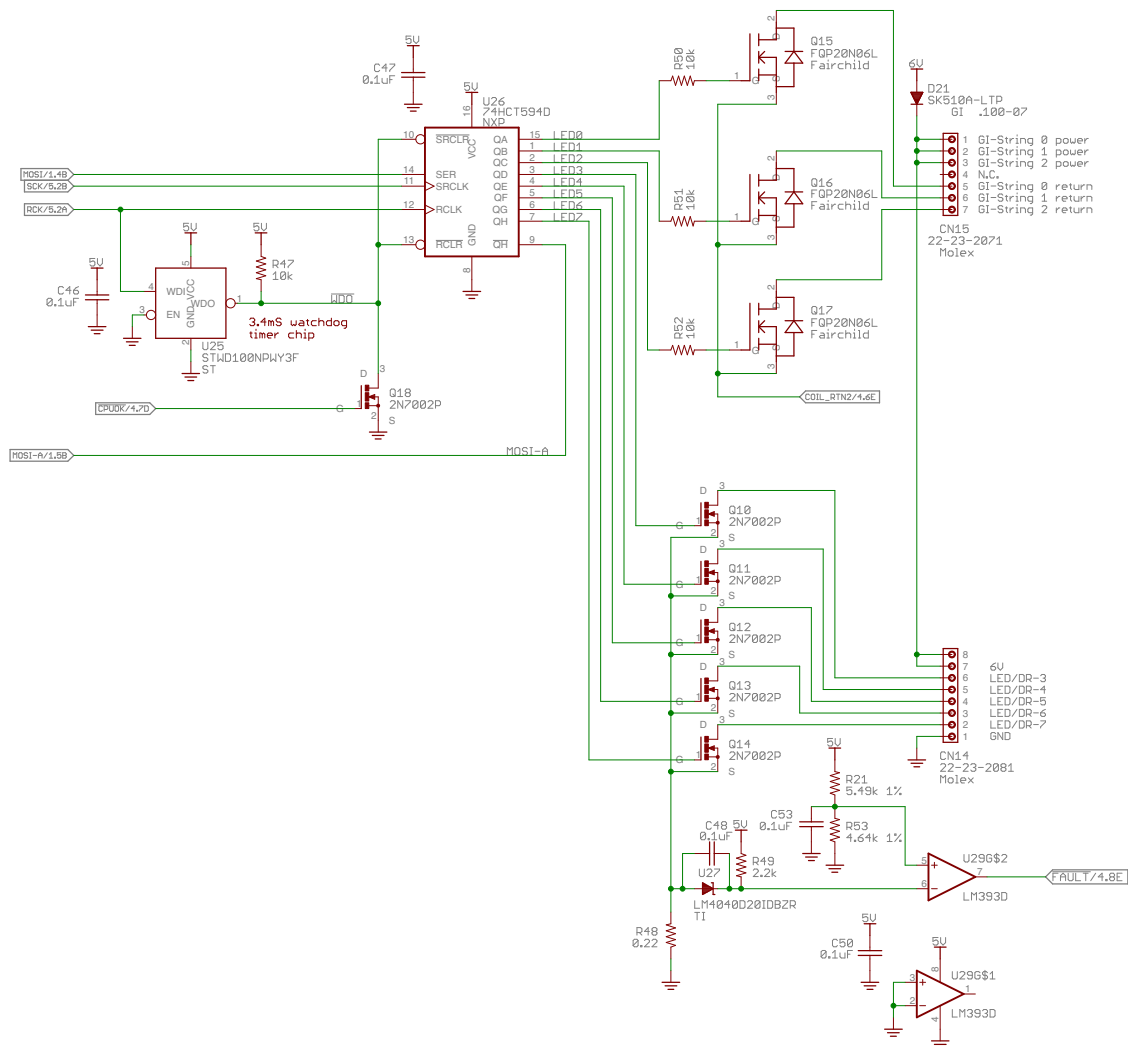


STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
		TITLE: 520-7017-72D	
Document Number:		REV:	
Power Supply			
Date: 2/25/19 2:48 PM		Sheet: 3/6	



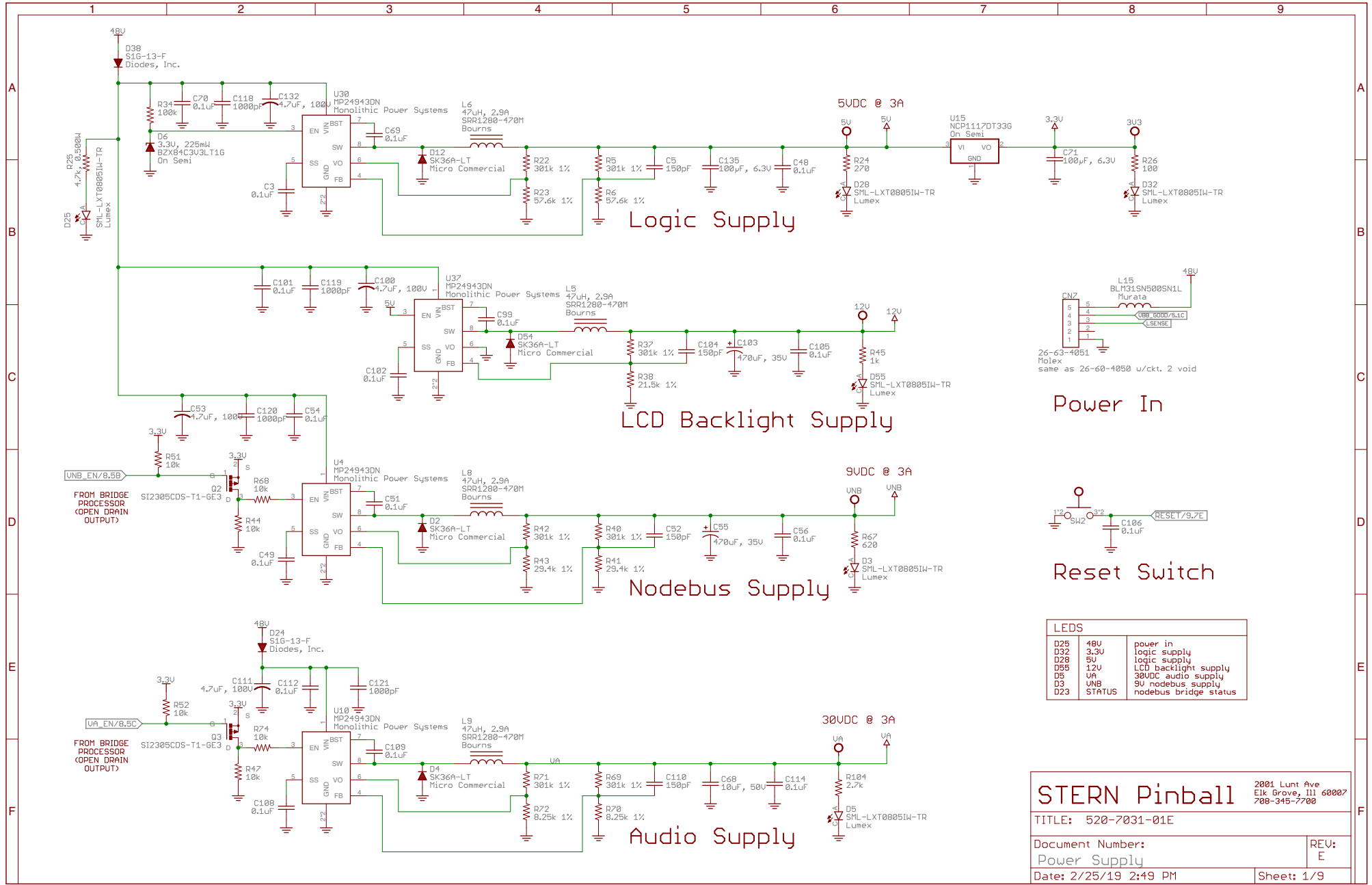


STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
TITLE: 520-7017-72D			
Document Number:			REV:
Switch Inputs			
Date: 2/25/19 2:48 PM			Sheet: 5/6



$I_{sense} = 2.048V + I_{led} \times 0.22\Omega$ (\leftarrow input of comparator)
 $U_{ref} = 5.0V \times 4.64k / (5.49k + 4.64k) = 2.29V$
 $I_{trip} = (2.29V - 2.048V) / 0.22\Omega = 1.1A$

STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-7017-72D		
Document Number:	REV:	
GI and LED/General Drives		
Date: 2/25/19 2:48 PM	Sheet: 6/6	

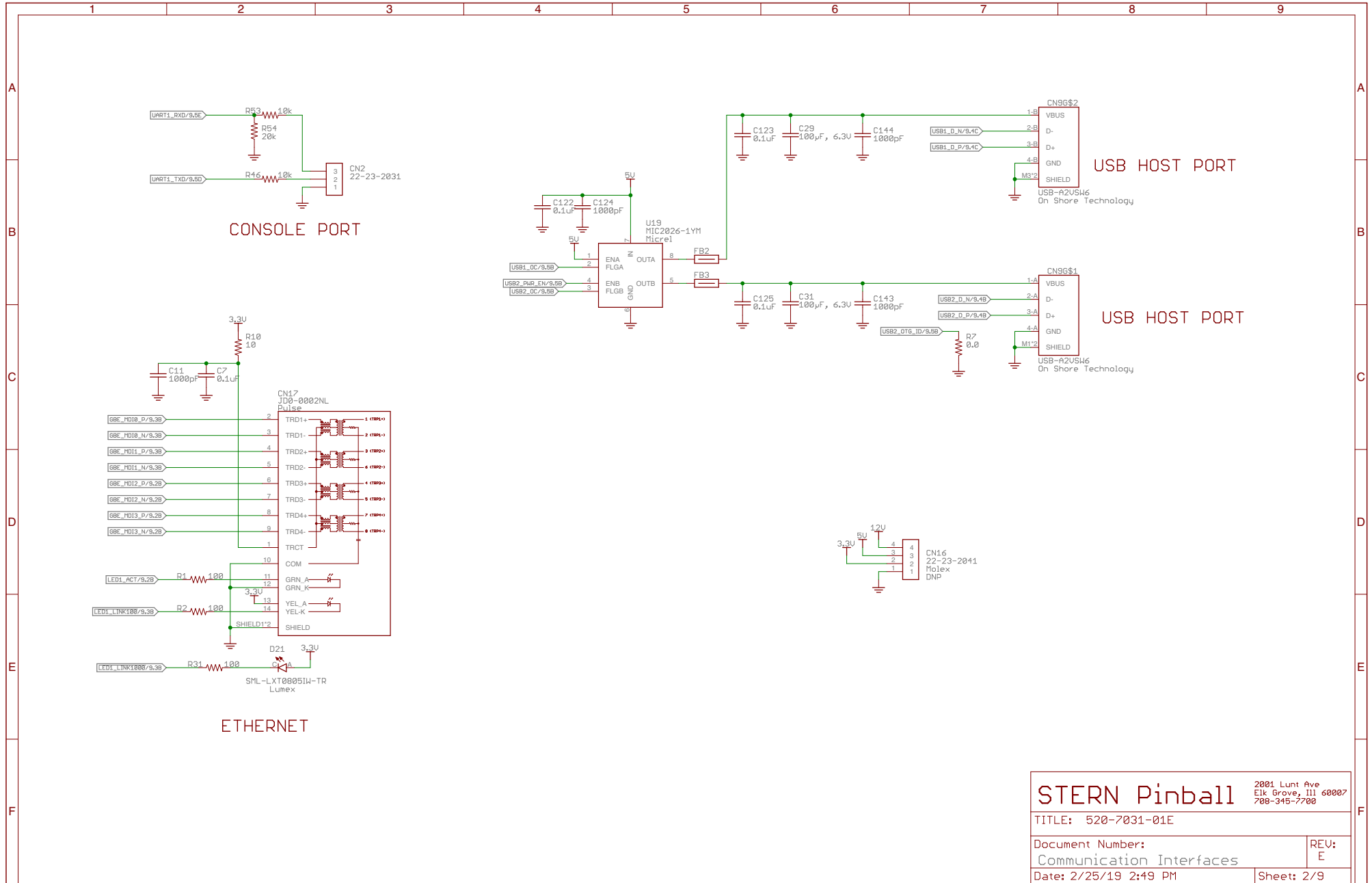


LEDS		
D25	48U	power in
D32	3.3U	logic supply
D28	5U	logic supply
D55	12U	LCD backlight supply
D5	VA	30VDC audio supply
D3	UNB	5U nodebus supply
D23	STATUS	nodebus bridge status

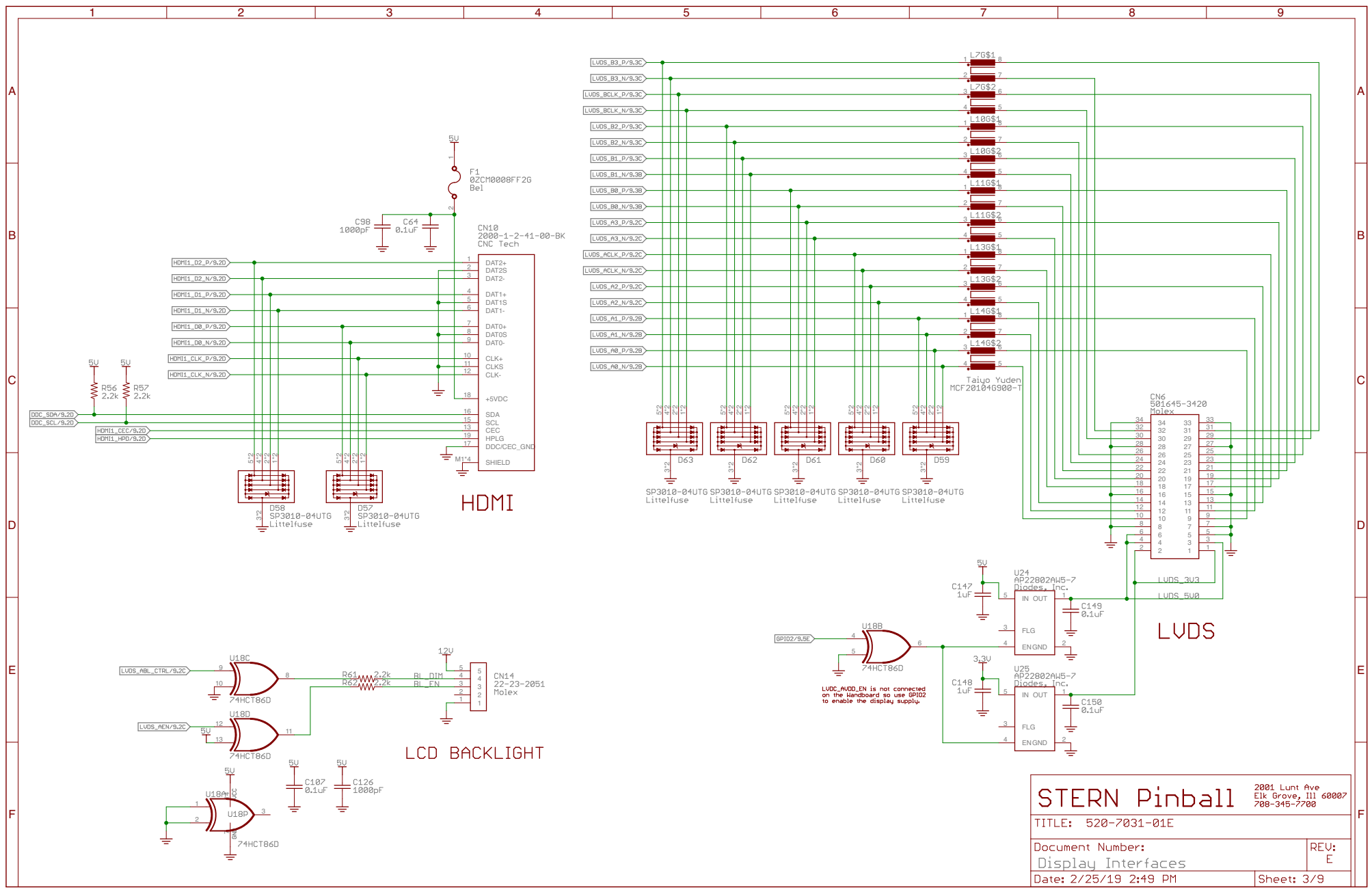
STERN Pinball 2001 Lunt Ave
Elk Grove, Ill 60007
708-345-7700

TITLE: 520-7031-01E

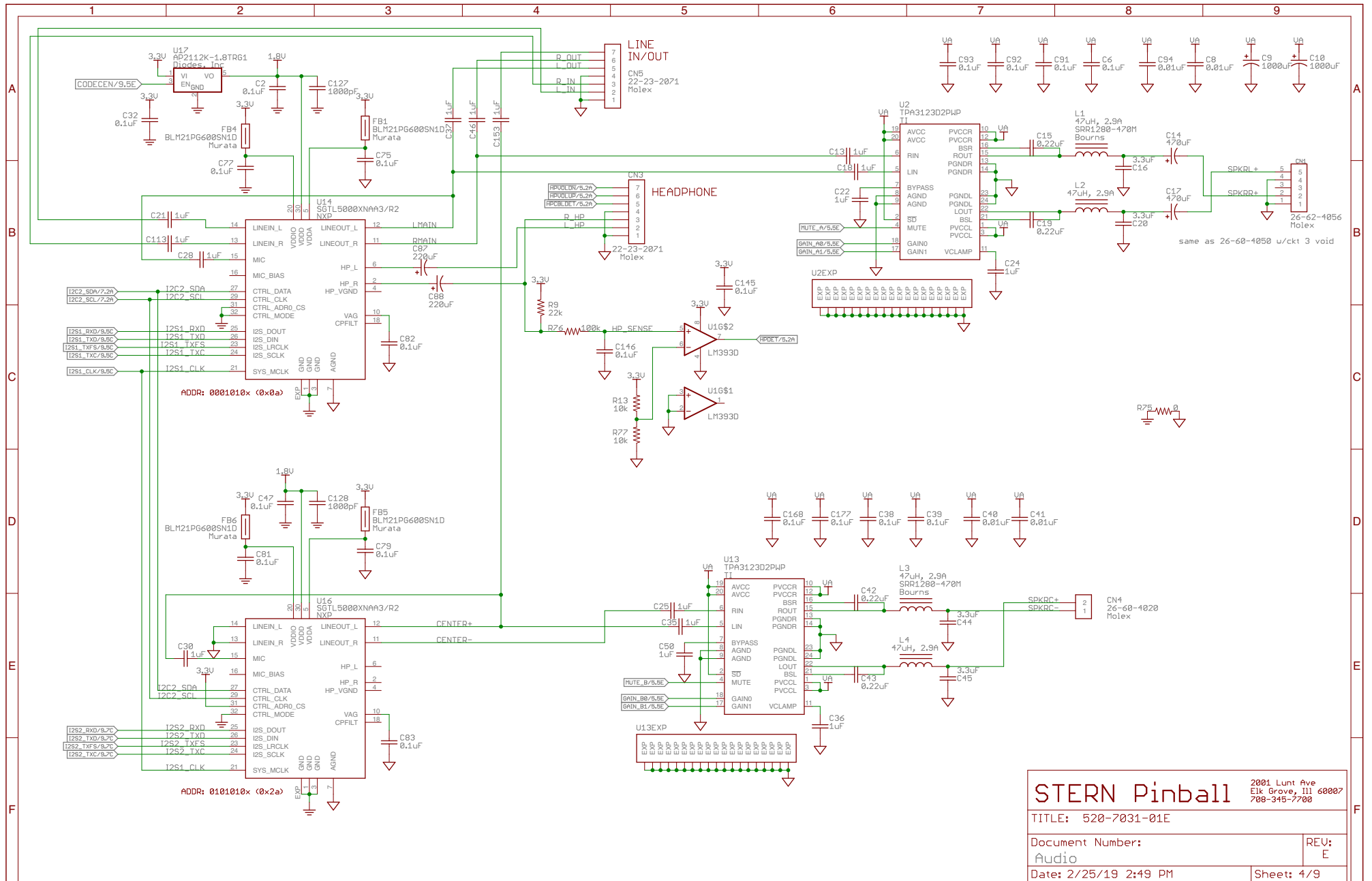
Document Number: Power Supply	REV: E
Date: 2/25/19 2:49 PM	Sheet: 1/9



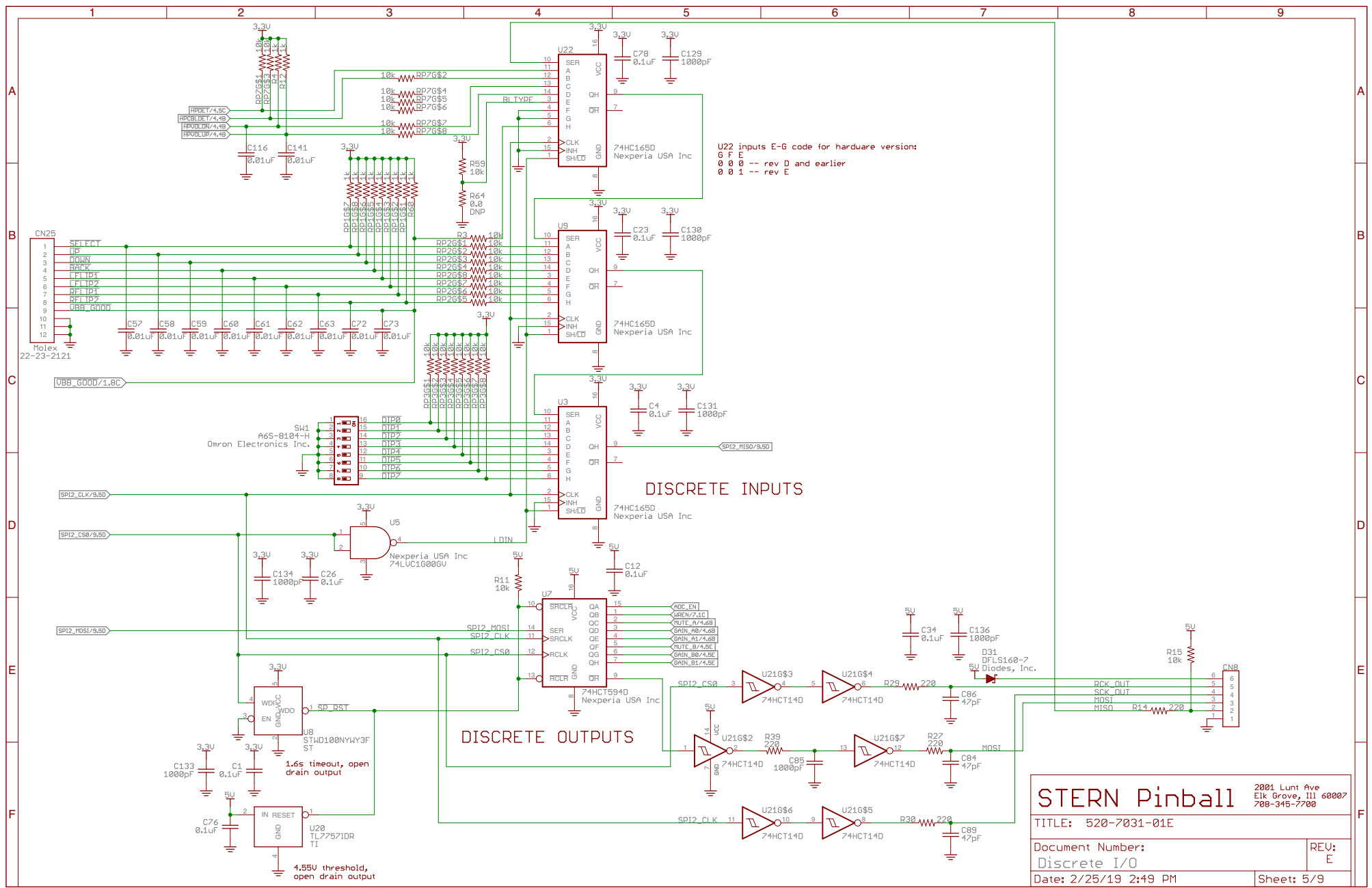
STERN Pinball 2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700		TITLE: 520-7031-01E	
		Document Number: Communication Interfaces	REV: E
Date: 2/25/19 2:49 PM		Sheet: 2/9	



STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-7031-01E		
Document Number:	Display Interfaces	REV: E
Date: 2/25/19 2:49 PM	Sheet: 3/9	



STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
TITLE: 520-7031-01E			
Document Number:			REV:
Audio			E
Date: 2/25/19 2:49 PM			Sheet: 4/9

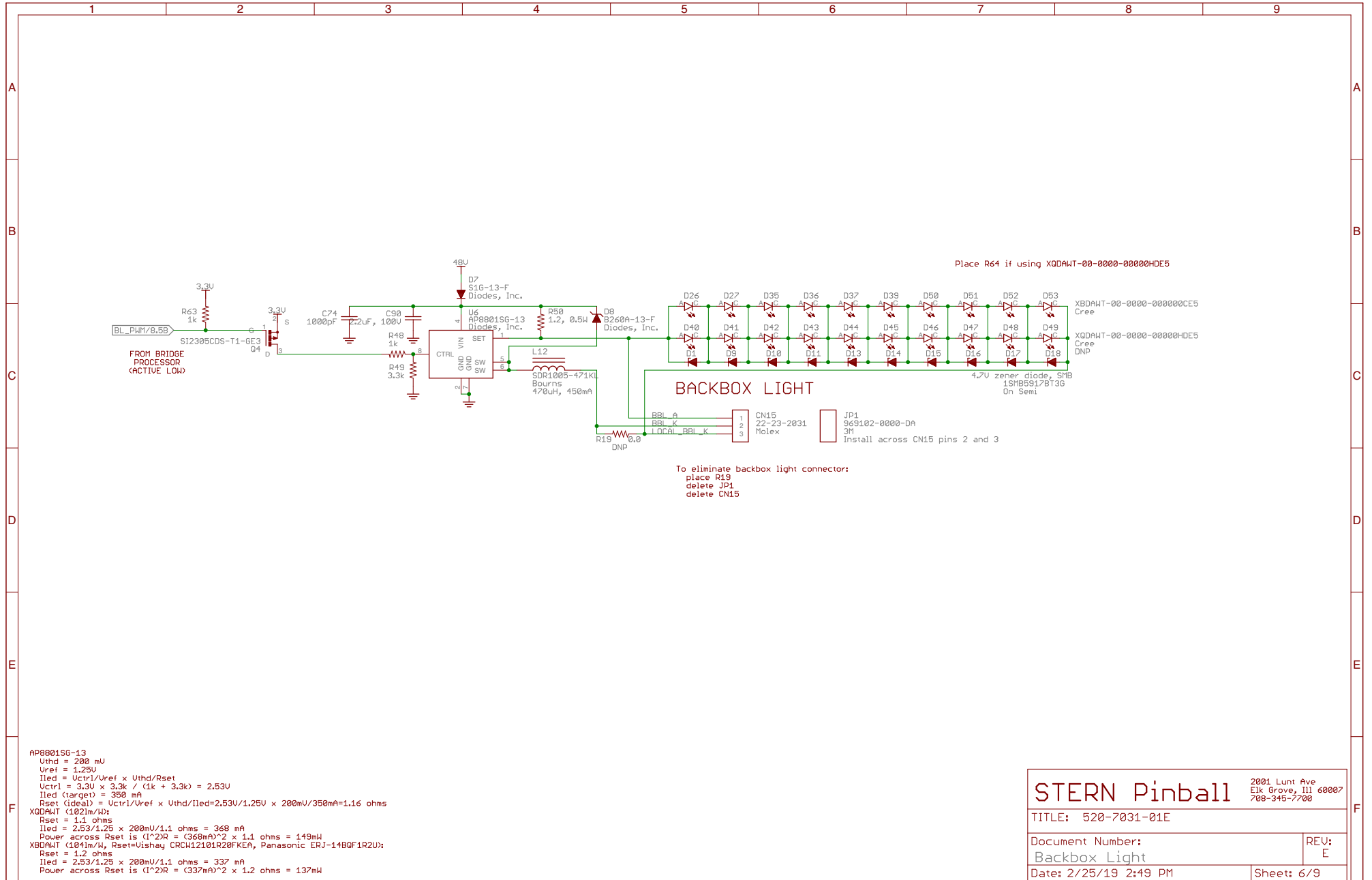


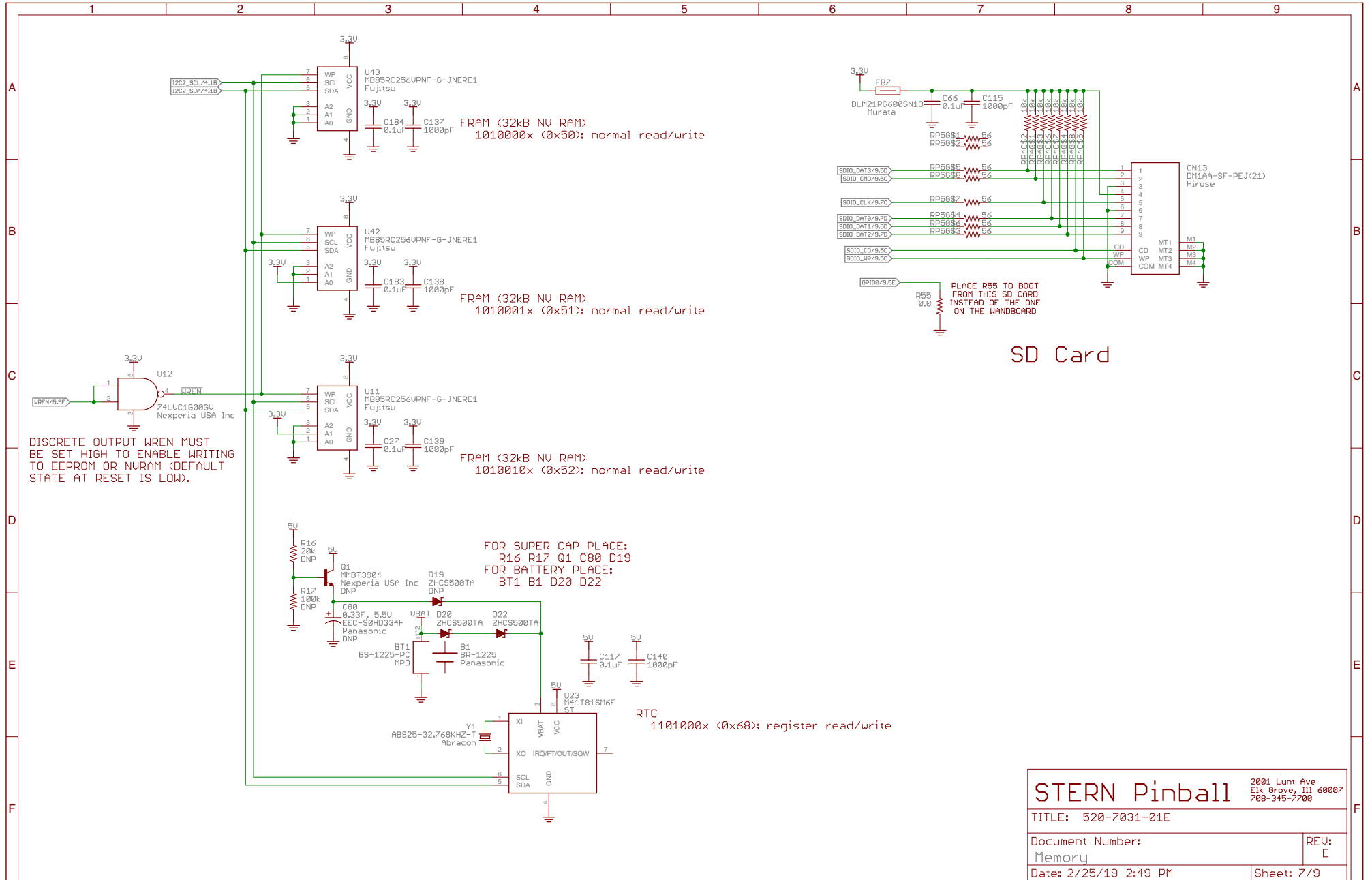
U22 inputs E-G code for hardware version:
 0 0 0 0 -- rev D and earlier
 0 0 1 -- rev E

DISCRETE INPUTS

DISCRETE OUTPUTS

STERN Pinball 2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700	
TITLE: 520-7031-01E	
Document Number: Discrete I/O	REV: E
Date: 2/25/19 2:49 PM	Sheet: 5/9





DISCRETE OUTPUT WREN MUST BE SET HIGH TO ENABLE WRITING TO EEPROM OR NURAM (DEFAULT STATE AT RESET IS LOW).

FRAM (32kb NU RAM)
101000x (0x50): normal read/write

FRAM (32kb NU RAM)
101001x (0x51): normal read/write

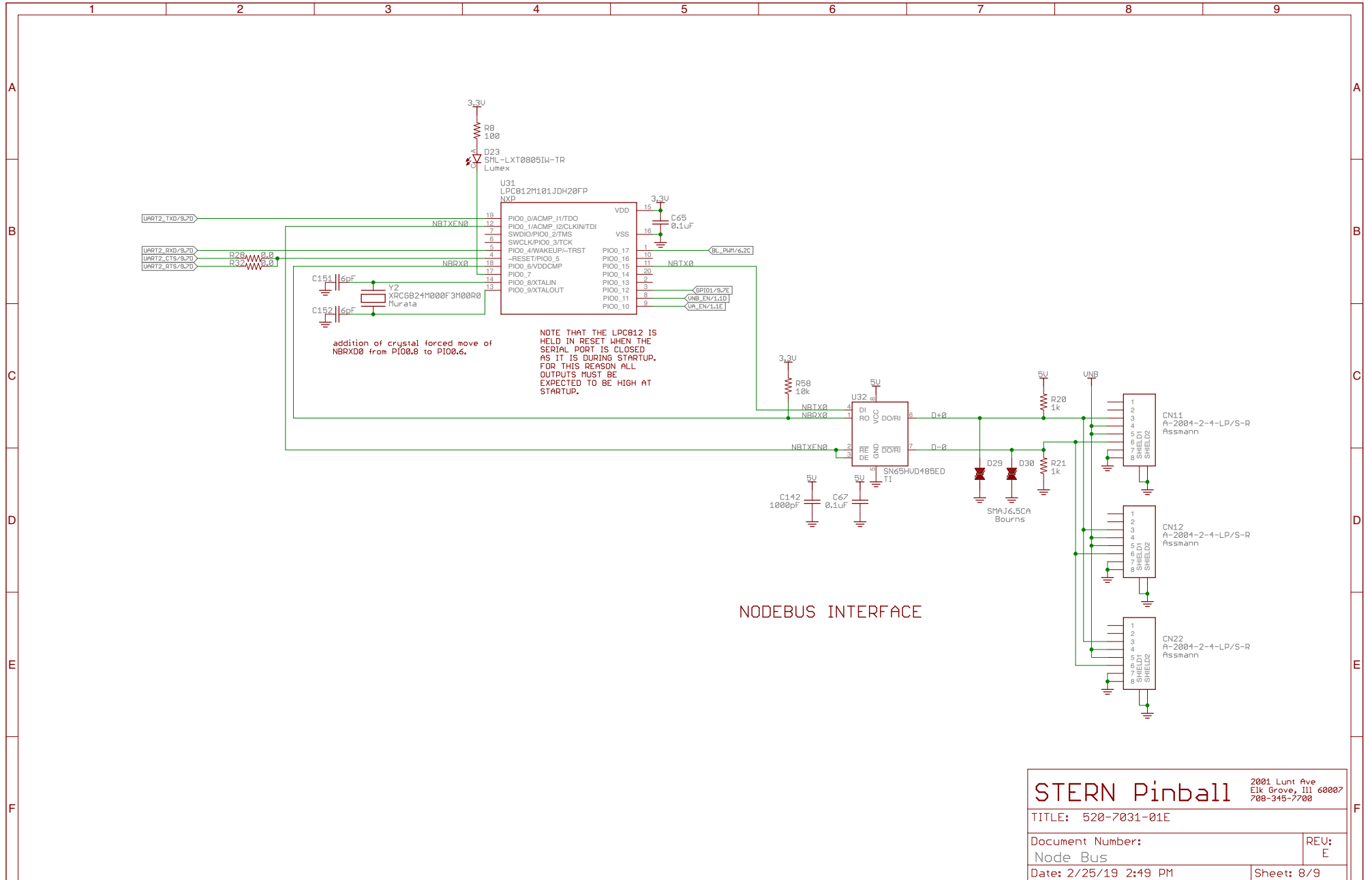
FRAM (32kb NU RAM)
1010010x (0x52): normal read/write

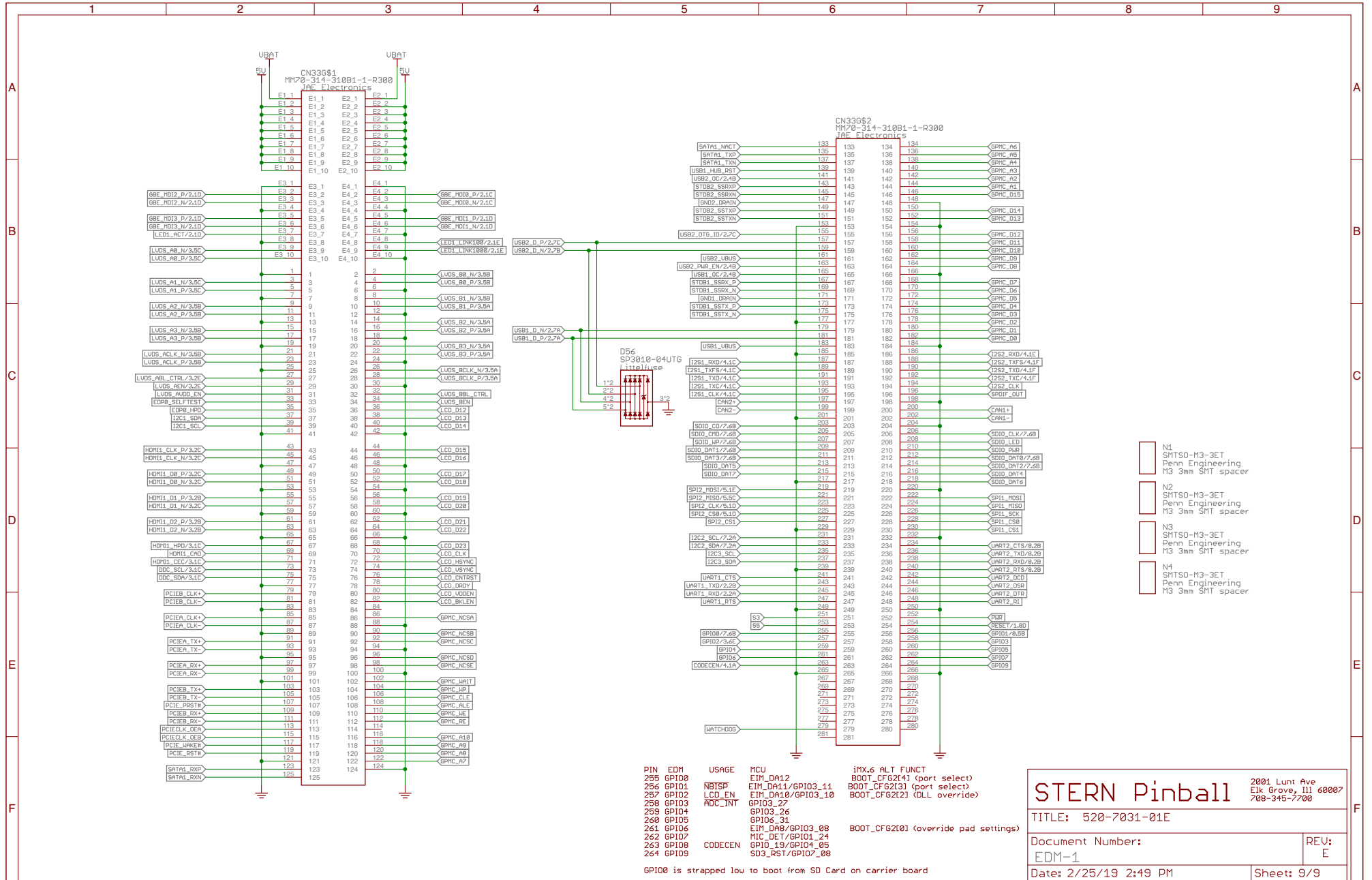
FOR SUPER CAP PLACE:
R16 R17 Q1 C80 D19
FOR BATTERY PLACE:
BT1 B1 D20 D22

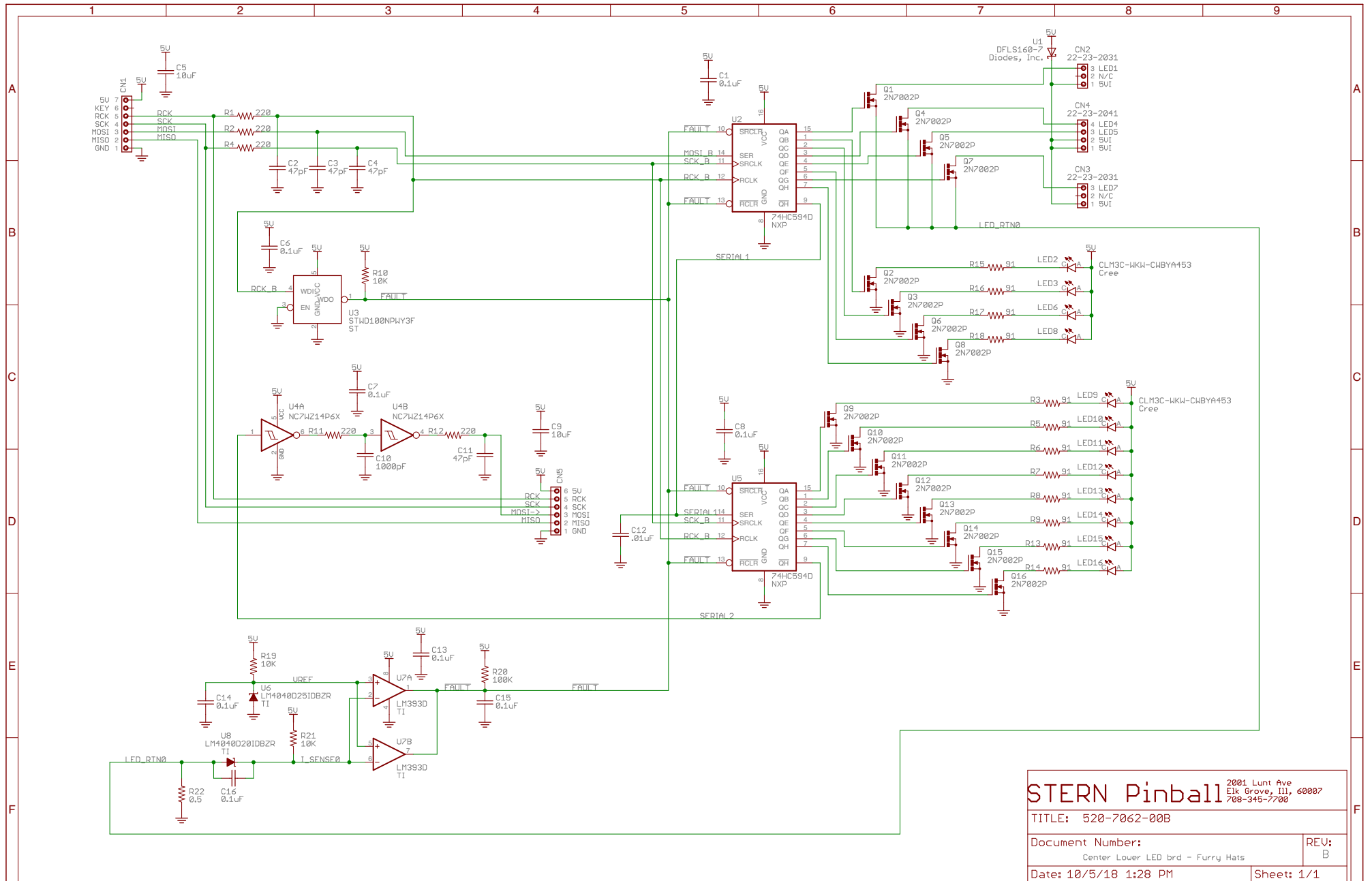
RTC
110100x (0x68): register read/write

SD Card

STERN Pinball		2001 Lunt Ave Elk Grove, Ill 60007 708-345-7700
TITLE: 520-7031-01E		
Document Number:	REV: E	
Date: 2/25/19 2:49 PM	Sheet: 7/9	







STERN Pinball 2001 Lunt Ave Elk Grove, Ill, 60007 708-345-7700	
TITLE: 520-7062-00B	
Document Number: Center Lower LED brd - Furry Hats	REV: B
Date: 10/5/18 1:28 PM	Sheet: 1/1