Control and Speaker Protection Board for F5X Power Amplifier

Xen Audio
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1. Circuit Description

1.1 Background

The control and protection board that has been offered for the F5X project is based on the circuit that we have been using for our own power amplifiers for the last 10 years. The only changes to the original version in this public version are

a) a new layout using SMD components to suit the F5X case,
b) replacing the diff pair P-JFETs (originally 2SJ109s) by P-MOSFETs due to availability,
c) addition of relay control jumpers as opposed to PCB wiring to allow more user flexibilities.

As already mentioned before, there are 100 ways to skin a cat. This is only how we would want to do so. The entire circuit is logic based, almost fully PCB hard wired, with no software involved and no microprocessors chips running on a digital clock signal. We consider this to be an essential feature for a protection circuit, for maximum reliability and minimum RF interference. The entire circuit essentially operates in quasi-static mode.

1.2 Functionalities

The protection board has two main functionalities – a controlled power up of the amplifier, and a controlled shut down in case a DC is detected at the amplifier outputs. We shall explain in a later section how we envisage controlled power up and shut down should be implemented.

1.3 User Interface and Operational Statuses

A single pushbutton on the front panel of the amplifier provides the only user interface. By pushing the push button, you can cycle between 3 states – OFF, Stand-By, ON (and then followed again by OFF, Standby, ….). During power up, the default status is OFF (safe state). The naming of the three states is arbitrary. You may equally name them as Power-Up, Warm-Up, and Operate respectively.

The three statuses are illustrated by the LED on the front panel. OFF = LED Off, Stand-By = LED Red; ON = LED Blue.

1.4 Power Up, Stand-By, Operate and Shutdown

Controlled power up means, in our case, that upon switching on the mains power switch (at the back of the amplifier), the auxiliary transformer will be powered up, and logic circuits in the protection board set to its default, safe values, before the mains transformer is switched on. As this happens, at least the first bank of capacitors will also receive voltage. In case you are using the originally intended CRegC configuration, the regulator is, at this stage, being turned off, so that there is no current consumption by the amplifier circuit. In case you are using the temporary CRC solution, the second bank of C will also receive voltage after a delay (as provided by the RC of the C-RC), and the amplifier will draw current. However, the inputs to the amplifier are muted, and the speakers disconnected, until further user command. At this stage, the amplifier is in the "OFF" state, even though it is energised in the (temporary) CRC version.

The controlled power up is necessary to make sure that the control & protection circuit is working properly before the main transformer is switched on. In-rush current is automatically limited by the NTC between the main transformer and the mains connections. Thus, the amplifier can be turned on in a safe manner without tripping any mains fuses.

Engaging the pushbutton once will change the control status to "Stand-By". This you may consider not essential, but it is, at least for us, a useful feature. Again in the CRegC version, the change to the Stand-By state will switch on the regulator, which has a built-in slow start feature. The second banks of C will get charged up slowly, and the amplifier will receive power and draw current. At this stage, the inputs to the amplifier are still muted, and the speaker disconnected. So you can in theory leave the amplifier in this stage for indefinite without fear of damaging your speakers. You will be keeping your living room warm with electrical heating.

A further engagement of the pushbutton will allow the amplifier to go into the ON state, or perhaps better described as the Operate state. The input mute is disabled, the speakers engaged shortly after (the input mute relays normally switches faster than the speaker relays), and the amplifier will play music.

To power down (by pushing the button once more), it is intended that inputs would be muted and speaker disengaged immediately. The regulators are tuned off with a small time delay, so that the amplifier will be gradually run down as the second bank of caps are emptied. The mains transformer, the first bank of caps, and the auxiliary power supply (for the control & protection board) are still energised. We consider it important that the inputs are muted and the speakers disengaged first, before the amplifier is power down, so as to avoid any undefined transient state which might cause a thump at the speakers.

Some people, like myself, prefer to keep their capacitors always charged, and you can certainly do so for the first bank of caps in the CRegC by leaving the amplifier in the "OFF" state indefinitely. The only current consumption would be leakage in the caps, the mains relay, as well as the control logic circuits.

To completely de-energise the amplifier, you can simply switch off the mains switch at the back, at your own leisure. We consider it a good habit to de-energise completely using the mains switch, instead of rely on some electronic logic to hold it in that state. One cannot be sure that the logic circuit will always function faultlessly, even in the presence of unforeseen interferences (e.g. from lightning pulse in mains supply).

1.5 Push Button Counter Circuit

Referring to the schematics published by Alexis Shaw, pushbutton P3 is switch debounced by R7 / C3, followed by Schmidt Trigger U4. The debounced signal is then used to cyclically switch a count-to-3 logic circuit formed by U2C, U3A, U3B. The two outputs from the counter are buffered by U1A, the output of which then drives the bi-colour LEDs as well as the downstream control circuits. The circuit around D1/R1/R2/C1 and D2/R3/R4/C2 ensures fast ON slow OFF to avoid undefined transient states. The output from U3A is Control Bit 1 (CB1), which corresponds to the Stand-By state. The output from U3B is control Bit 2 (CB2), the ON, or Operate, state.

U2B is used to set both U3A and U3B to zero output (OFF state) during Start-Up and in case the protection circuit trips in to shut off the amplifier. The Start-Up circuit is a simple R-C time delay triggering a comparator (U11, R41-45, C20). The user can easily change the start-up delay time by simply changing the R-C time constant.

U13B is an NOR gate, the output of which drives all the relays which are ONLY to be activated in the ON state, but NOT in the Stand-By State. The output of U13A, on the other hand, drives all the relays which are to be activated BOTH in the Stand-By state and the subsequent ON State. These two output lines (U13A, U13B) are active when logically low.

1.5 Relay Control

In addition to the above control lines, there are two further signals which can activate / deactivate the relays. They are SUD (Start Up Delay) and TRIP (in case of amplifier output DC detected, or Speaker Protection).

As mentioned at the beginning, the F5X protection board allows the user the flexibility to control any relay with any of the 4 control lines, by the use of jumpers. The only exception is the Mains Relay (MR), which is intentionally only controlled by SUD and TRIP. Once can argue whether this has to be the case, or whether the mains relay can be configured to operate differently. This is what we like to use for ourselves. But you are free to configure it differently by using one of the configurable relay drivers instead.

6 Relays are User configurable on the PCB, namely :

ISR1 (Input shunt relay 1)
ISR2 (Input shunt relay 2)
RSR1 (regulator shunt relay 1)
RSR2 (regulator shunt relay 2)
LSP1 (loudspeaker protection relay 1)
LSP2 (loudspeaker protection relay 2)

The four control lines are labelled as :
CB1 (This actually means BOTH the LED Red and the LED Blue states)
CB2 (Equivalent to LED Blue state ONLY, essentially Operate)
SUD (start-up delay)
TRIP (emergency shutdown, fault detected)

To render a particular control signal effective for a particular relay, the user needs to connect the middle column of the jumper array to the “ON” column. This should actually be named as “Effective”, but the word is too long to silk screen on the PCB, thus the somewhat unfortunate use of the word “ON”. For any control signal that should be ineffective, it should NOT be left open, but connected to the “OFF” or “Ineffective” column.

For our own use, this is how we configure the relays :

ISR1	CB1 OFF	CB2 ON	SUD ON	TRIP ON
ISR2	CB1 OFF	CB2 ON	SUD ON	TRIP ON
RSR1	CB1 ON	CB2 OFF	SUD ON	TRIP ON
RSR2	CB1 ON	CB2 OFF	SUD ON	TRIP ON
LSP1	CB1 OFF	CB2 ON	SUD ON	TRIP ON
LSP2	CB1 OFF	CB2 ON	SUD ON	TRIP ON

But as long as you understand the logic behind, you can freely choice how you want to configure them.

1.6 Relay Driver Circuit

Take the example of RSR1 configured as suggested above. The three active inputs to the NOR gate U9A are CB1, SUD and TRIP. The forth input (CB2) is grounded by the OFF jumper. For the output of U9A to go high to turn on the relay, ALL 3 active inputs have to be low at the same time, i.e. the start-up delay has elapsed, there is no DC at the amplifier output detected, and the user has selected the Stand-By or Operate state. Should any of these control lines goes high (e.g. before start-up time is elapsed, or there is a fault detected), the relay will be turned off by the switching MOSFET Q2. R24 is a tie-down resistor to make sure of the default state of the relay, and R17 is a gate stopper to prevent any oscillation at the MOSFET under transient conditions. Again one can argue whether they are absolutely essential. We have them in our design over 10 years, and we don't want to change anything that works.

For the power relays (LSP1, LSP2 and MR), the switching MOSFETs are TO220 devices mounted on heat sink. So they will be more than sufficient to switch any current that the Auxiliary PSU is capable of supplying.

1.7 Fault Detection

To detect any DC voltage across the F5X amplifier differential output, a discrete long tail pair (LTP) has been used for each of the two channels. Our own original circuit uses 2SK109BLs which are now unobtainium and extraordinarily expensive. Therefore, SMD P-MOSFETs such as ZVP3310 are used as replacements. If these are poorly matched, there might be a slight difference in fault trigger level between a positive and a negative DC input voltage. So if one wants to be perfect, one should match the MOSFETs at about 2mA. The use of degeneration resistors R33 / R34 helps to make this mismatch much less critical than otherwise. In practice, a difference in DC trigger level of a few tenths of a volt is of no consequence. Either the amplifier has a blown output device, and the DC will go way high or low (towards the rails), or it will be way below 0.1V if the amplifier is functional and adjusted properly.

The LTP consists of a biasing resistor R32, which determines the current through the LTP and hence the normal output voltage level at R39 / R40. This should be roughly about 2.5V. The gain of the LTP is determined by the degeneration resistors R33 / R34, and Yfs of the MOSFETs, and the drain resistors R39 / R40. This is set to be about 2.5, so that a 2V pk-pk DC offset at the diff pair input will be sufficient to trigger the fault detection. If you wish to have a more sensitive trigger, you may increase the gain of the LTP by decreasing the values of R33 / R34, while adjusting R32 to reset the normal (no DC at input) output voltage to around 2.5V. A set of possible values could be 120R for R33 / R34, and 2k for R32. The said values were tested on one board as effective and performed as expected.

The potential dividers R35-R38 are essential as the maximum possible voltage of the amplifier output (pk-pk) is larger than that of the AUX PSU. The potential divider will thus make sure the input voltage seen by the LTP inputs is within bounds. Like in many opamps, D5, D6 are incorporated to limit excessive voltage across the MOSFETs to prevent accidental damage. C15-C18, together with R35-R38, form two input low pass filters, so that only the DC content below 0.16Hz reaches the LTP. If you wish to have a faster response, you can simply lower the value of C15-C18. Do bear in mind that too fast a response might trip your amplifier when you play music with low frequency content real loud. Like so often in life, it is a compromise between safety and performance. Also take note that as indicated in the Mains Power Supply schematics, the Gnd connections of both F5X amplifiers and the Gnd connection of the protection board **should under no circumstances be connected together**. The word Gnd only means an arbitrary reference voltage. In actual fact, the protection PCB (logic) Gnd is approximately 12V below the amplifier Gnd connections.

The two small signal diodes D7, D8 essentially forms a discrete OR gate, so that both outputs of the LTP (or Amplifier output DC of either polarity) can trigger the fault detection circuit downstream. The detection is done by the comparator U5. An extra pull-down resistor R10 set the default to low (safe), and the trigger level is set by R8 / R11 to 4V. Although this trigger level functions without problems in our first F5X protection prototype, we have been informed that the variations in MOSFET Yfs are so large that in some cases the trigger level is not reached. If that is the case, you can fine adjust the trigger level by changing the ratio of R8 to R11. For example, you can temporary wire a 5k trimpot to the pads for R8 on the PCB, test and adjust the trigger level to your satisfaction, before removing the trimpot and replace it with a fixed resistor of appropriate value. The trigger can be easily measured at the output of U5, to which a pull-up resistor R9 is connected, as required by the comparator. The comparator is connected to both LTPs of the left and right channels. Thus, any one channel at fault will trigger the fault detection.

Once the fault detection is triggered, the faulty status has to be latched until it is reset manually. The latching is performed by U6A in parallel with U6B (as double safety, since the extra D-FF would otherwise be unused anyhow). U1B then provides a buffer output of the TRIP signal at logic level.

To reset the faulty status, one can momentarily short circuit pin 3 & 4 of the terminal block P4 (e.g. by means of an external push button) pulling pin 3 of U2A high to put the latch back to its start-up state. Alternatively, shutting off the amplifier at the mains switch, and switching on again after 1 minute, should have the same effect. In case of a fault detected, it is recommended that you should disconnect both speakers anyhow, before you proceed to locate and identify the origin of the defect.

Bill of Materials For F5X Speaker Protection Board - GB1

Designator	Description	Comment	Footprint	Digikey Part Number	Quantity
C1, C2	Ceramic 3.3uF Capacitor - 1206 , 25V, X7R	1206-3.3uF	1206	445-4029-1-ND	2
C3	Ceramic 0.1uF Capacitor - 1206, 50V, X7R	1206-0.1uF	1206	490-1775-1-ND	1
C4, C5, C6, C7, C8, C9, C11, C12, C13, C14, C19, C23, C24, C29, C33, C34	Ceramic 1.0uF Capacitor -1206, 50V, X7R	1206-1uF	1206	455-4105-1-ND	16
C10	Ceramic 100uF Capacitor - 1210, 10V, X5R	C1210-100uF	1210	587-1965-1-ND	1
C15_L, C15_R, C16_L, C16_R, C17_L, C17_R, C18_L, C18_R, C21, C22, C25, C28, C32, C35	Ceramic 10uFCapacitor - 1210, 35V, X7R	C1210-10uF	1210	587-2779-1-ND	14
C20	Ceramic 47uF Capacitor - 1210, 10V, X5R	C1210-47uF	1210	490-5312-1-ND	1
C26, C27, C30, C31	SMD-V Aluminum Electrolytic Capacitors, FT-Series 820uF 25V	820uF/25V	EEE-G	PCE5011CT-ND	4
D1, D2, D3, D4, D7_L, D7_R, D8_L, D8_R	1N4148 in SOD-323 package	1N4148	SOD-323	1N4148WSFSCT-ND	8
D5_L, D5_R, D6_L, D6_R	Red LED 0805	HSMC-C170	2.0X1.25X0.8	516-1428-1-ND	4
D9	Bi-color 3mm Common-Cathode R/B LED	N300TBR2D	R/B LED		1
D10, D11	1A Schotky Bridge Rectifier, 60V - MB16S	MB16S	MBS-1	MB16S-TPMSCT-ND	2
P1, P2, P4, P5, P6, P7	MOLEX 530150410 board header right angle	530150410	MOLEX 53015410	WM18981-ND	6
P3	Momentary microswitch - Racon8 gullwing	Racon 8	Racon 8 gullwing	CKN9363CT-ND	1
Q1, Q2, Q3, Q4	N-Channel Enhancement Mode Vertical DMOS FET in SOT-23	2N7002	SOT23	568-5981-1-ND	4
Q5, Q6, Q9	HEXFET N-Channel Power MOSFET in TO220	IRF610	TO-220AB	IRF610PBF-ND	3
Q7_L, Q7_R, Q8_L, Q8_R	ZVP3310F - P-Channel Enhancement Mode Vertical DMOS FET	ZVP3310F	SOT23	ZVP3310FCT-ND	4
R1, R3	1206, 499 ohm, chip resistor	1206-499R	8-1206	541-499FCT-ND	2
R2, R4, R5, R6, R12, R14, R23, R24, R25, R26, R27, R28, R29, R51	1206, 4.99K ohm, chip resistor	1206-4.99K	8-1206	541-4.99KFCT-ND	14
R7, R16, R17, R18, R19, R20, R21, R22, R35_L, R35_R, R36_L, R36_R, R37_L, R37_R, R38_L, R38_R, R44	1206, 100K ohm, chip resistor	1206-100K	8-1206	541-100KFCT-ND	17
R8, R9, R42, R43	1206, 2.49K ohm, chip resistor	1206-2.49K	8-1206	541-2.49KFCT-ND	4
R10	1206, 24.9K ohm, chip resistor	1206-24.9K	8-1206	541-24.9KFCT-ND	1
R11, R13, R30, R31, R45, R48, R49, R50	1206, 10.0K ohm, chip resistor	1206-10K	8-1206	541-10.0KFCT-ND	8
R15	1206, 3.3K ohm, chip resistor	1206-3.3K	8-1206	541-3.32KFCT-ND	1
R32_L, R32_R	1206, 2.0K ohm, chip resistor	1206-2.7K	8-1206	541-2.00KFCT-ND	2
R33_L, R33_R, R34_L, R34_R	1206, 120 ohm, chip resistor	1206-300R	8-1206	541-120FCT-ND	4
R39_L, R39_R, R40_L, R40_R	1206, 1.24K ohm, chip resistor	1206-1.21K	8-1206	541-1.21KFCT-ND	4
R41	1206, 412K ohm, chip resistor	1206-390K	8-1206	541-392KFCT-ND	1
R46, R47	1206, 619 ohm, chip resistor	1206-620R	8-1206	541-620FCT-ND	2
U1	74HC367 - Hex Bus Driver with 3-State Outputs - TSSOP	SN74HC367PW	TSSOP-16L	296-28456-1-ND	1
U2, U13	74HC02 - Quadruple 2-Input Positive-NOR Gate - TSSOP	SN74HC02PW	TSSOP-14L	296-8206-1-ND	2
U3, U6	74HC74 - Dual D-Type Positive-Edge-Triggered Flip-Flop - TSSOP	SN74HC74PW	TSSOP-14L	296-8372-1-ND	2
U4	74HC1G14 - Schmitt-Trigger Inverter SOT-353-5L	74HC1G14GW	SOT353-5L	568-2641-1-ND	1
U5, U11	LT1716 - Precision rail-to-rail Comparator SOT-23-5L	LT1716	SOT95P285X100-5L	LT1716HS5#TRMPBFCT-ND	2
U7, U8, U9, U10	74HC4002 - Dual 4-Input Positive-NOR Gate TSSOP	CD74HC4002PW	TSSOP-14L	595-CD74HC4002PWR	4
U12	7805 - +5V 1A Regulator - TO220	L7805ABV	TO220ABN	497-2947-5-ND	1
U14	7812 - +12V 1A Regulator - TO220	L7812ABV	TO220ABN	497-1449-5-ND	1
U15	7912 - -12V 1A Regulator - TO220	L7912ABV	TO220V	497-1475-5-ND	1
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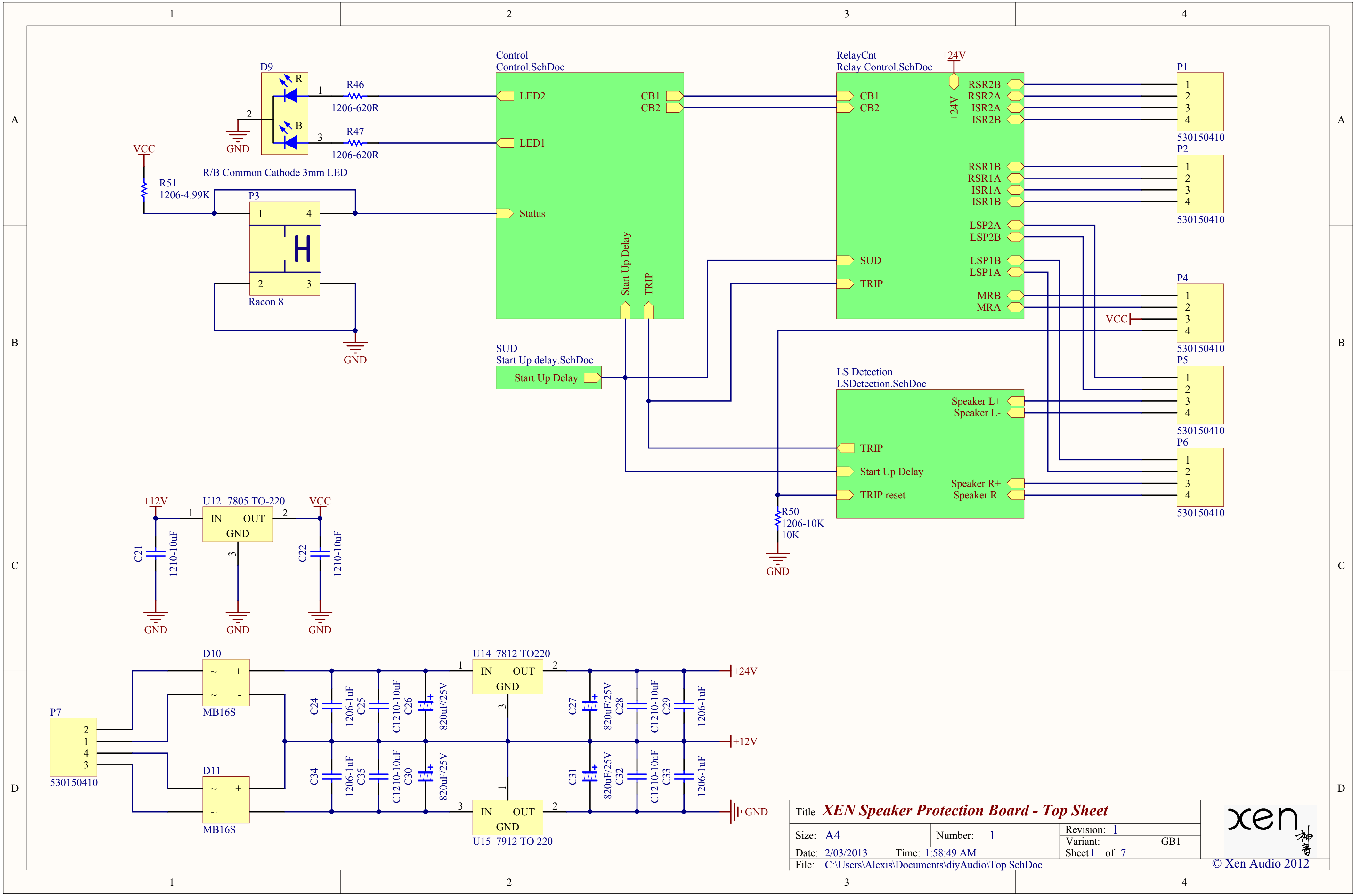
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B
R/B Common Cathode 3mm LED
R46
1206-620R
R47
1206-620R
GND
VCC
R51
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P3
Racon 8
Control
Control.SchDoc
LED2
LED1
Status
CB1
CB2
Start Up Delay
TRIP
RelayCnt
Relay Control.SchDoc
+24V
CB1
CB2
SUD
TRIP
RSR2B
RSR2A
ISR2A
ISR2B
RSR1B
RSR1A
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LSP2B
LSP1B
LSP1A
MRB
MRA
P1
P2
P4
P5
P6
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VCC
SUD
Start Up delay.SchDoc
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Speaker L+
Speaker L-
TRIP
Start Up Delay
TRIP reset
Speaker R+
Speaker R-
R50
1206-10K
10K
+12V
U12 7805 TO-220
IN OUT
GND
C21
1210-10uF
C22
1210-10uF
D10
MB16S
D11
MB16S
P7
530150410
U14 7812 TO220
U15 7912 TO 220
C24 1206-1uF
C25 C1210-10uF
C26 820uF/25V
C27 820uF/25V
C28 C1210-10uF
C29 1206-1uF
C34 1206-1uF
C35 C1210-10uF
C30 820uF/25V
C31 820uF/25V
C32 C1210-10uF
C33 1206-1uF
+24V
+12V
GND
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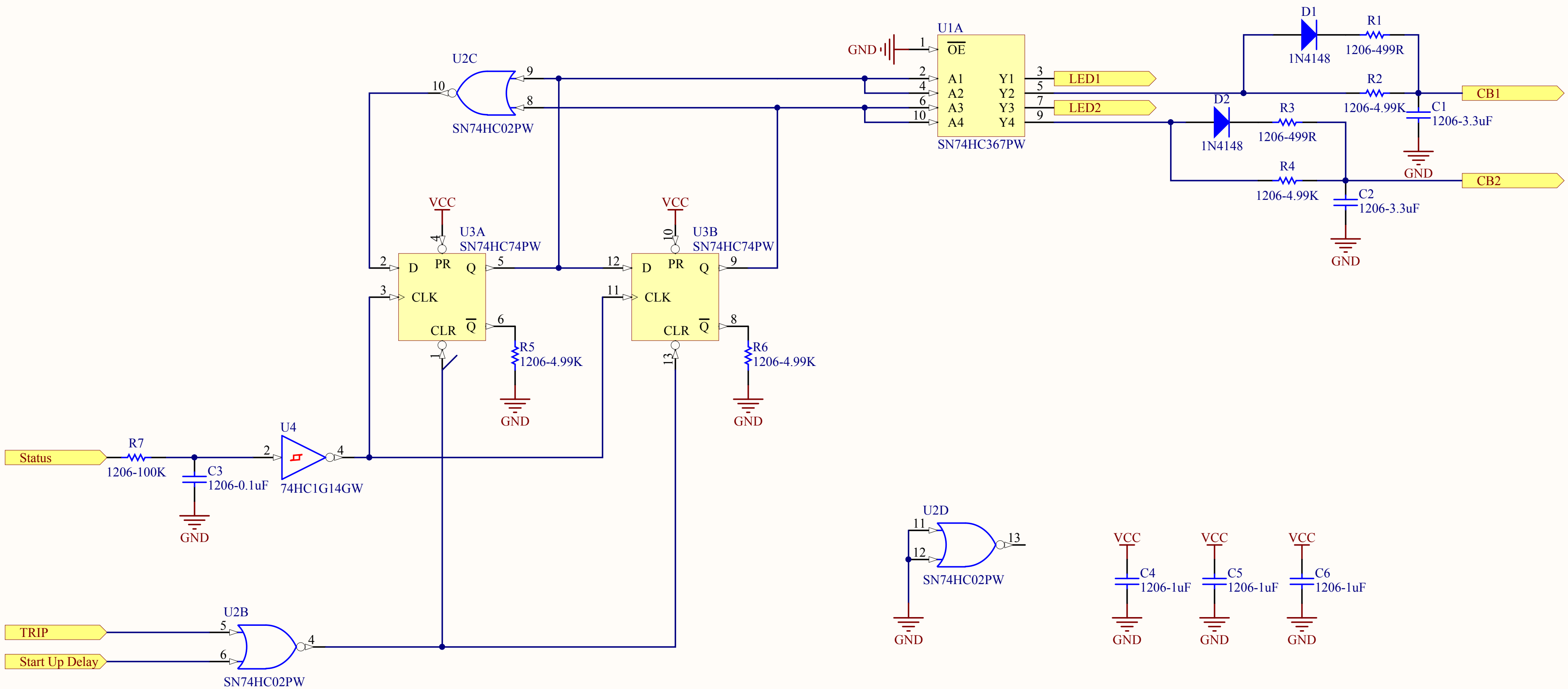

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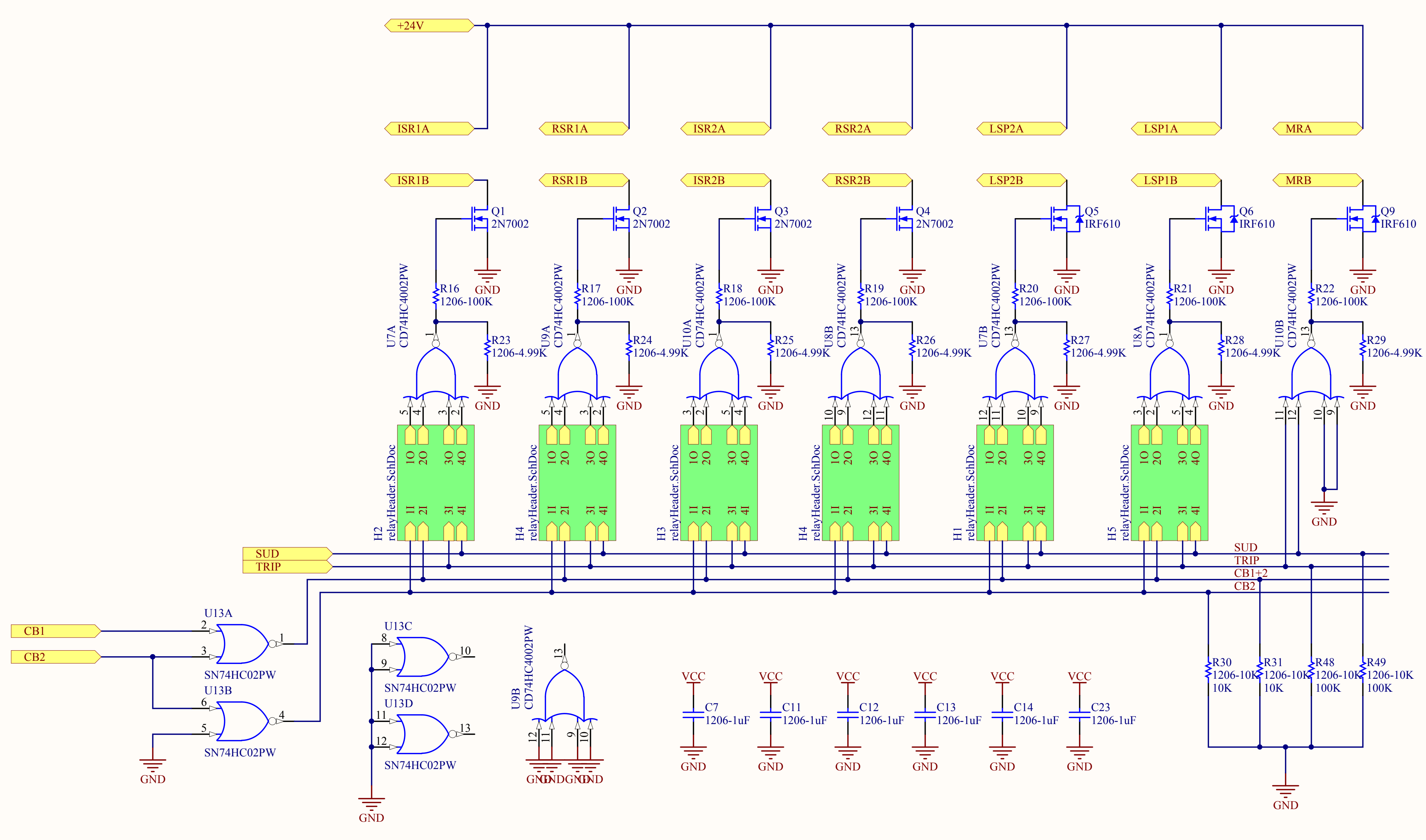

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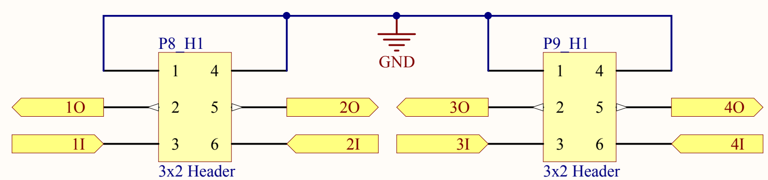

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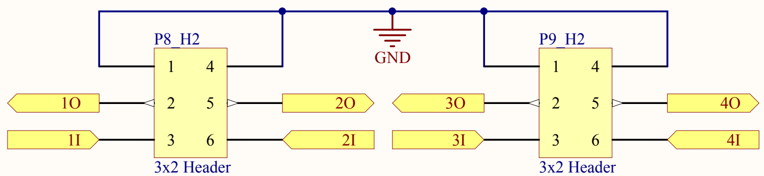

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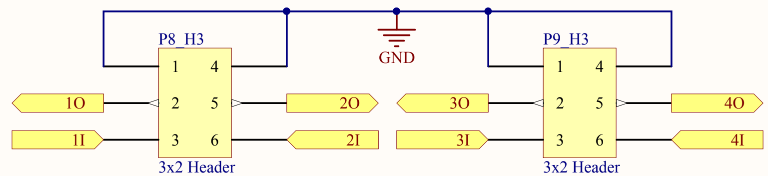

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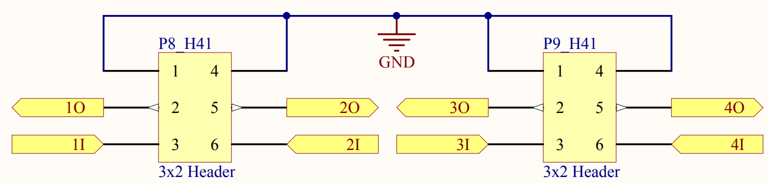

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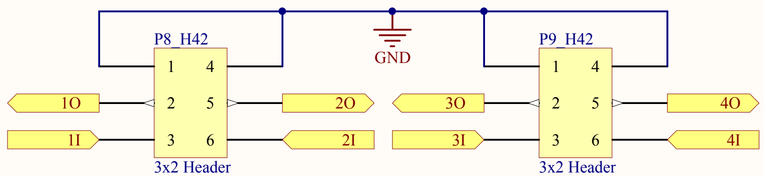

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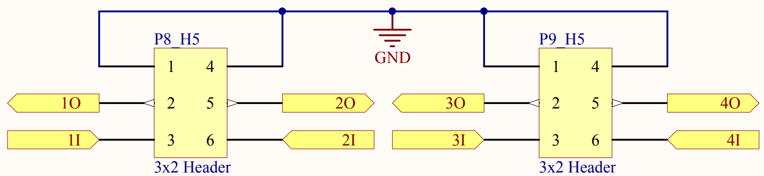

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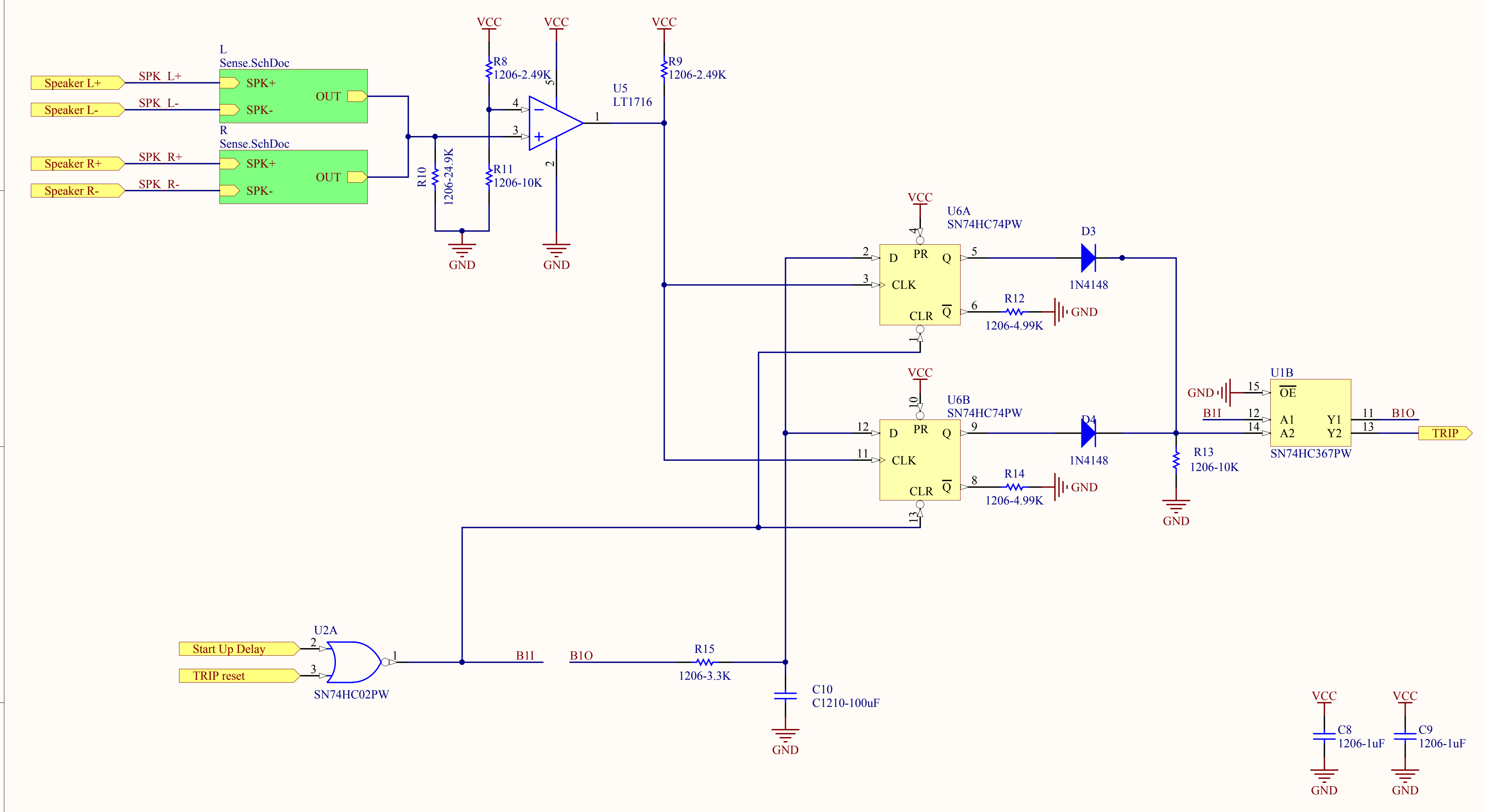

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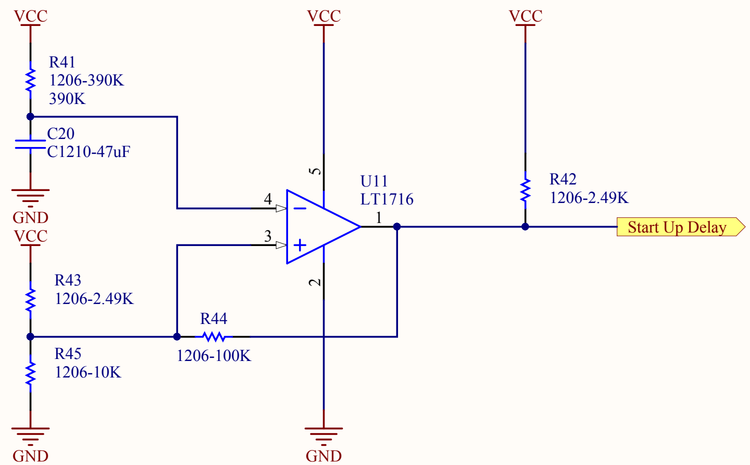
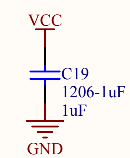
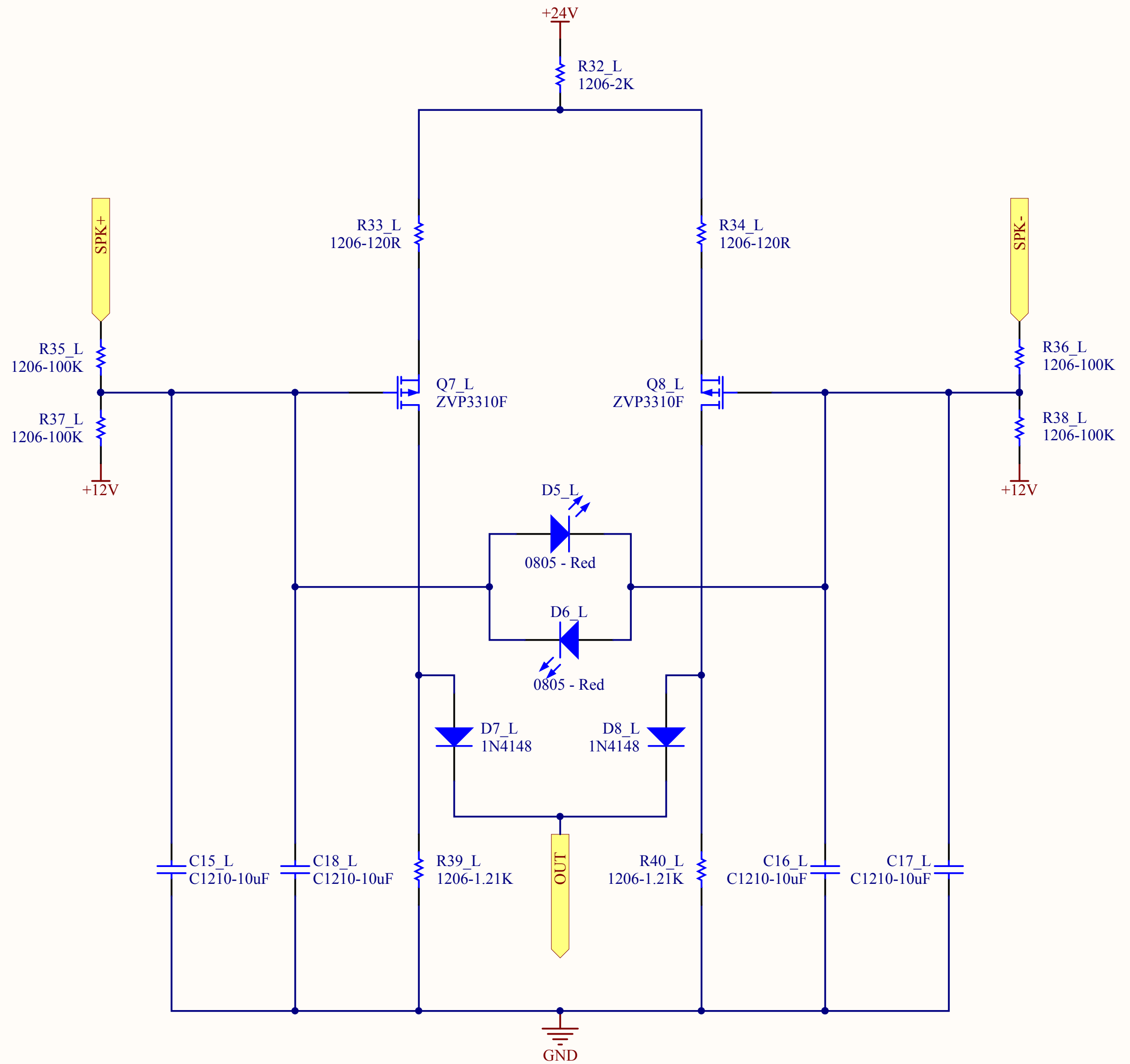


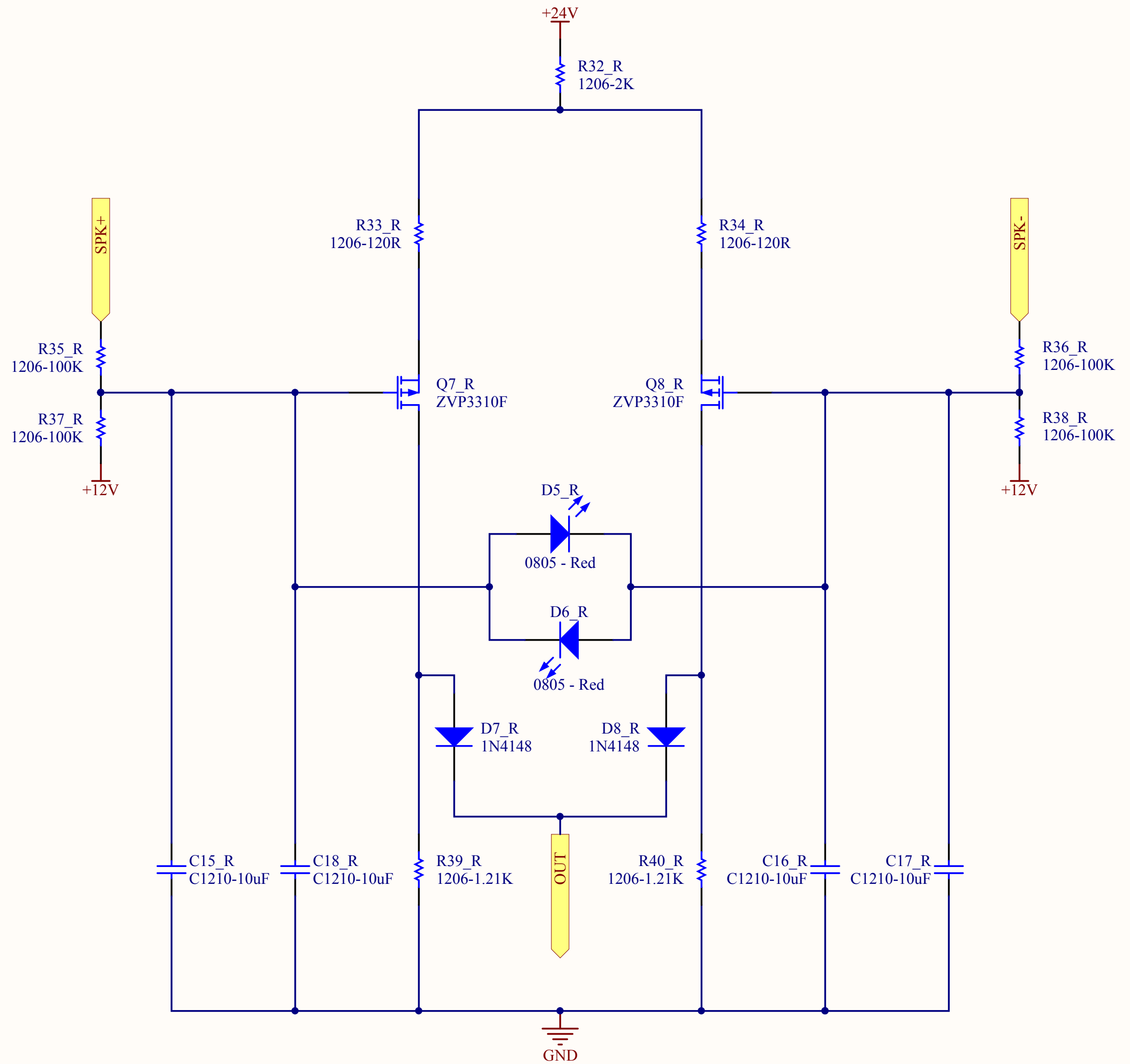


Title *XEN Speaker Protection Board - Start Up Delay*			
Size: A4	Number: 1	Revision: 1 Variant: GB1	
Date: 2/03/2013	Time: 1:58:51 AM	Sheet 6 of 7	
File: C:\Users\Alexis\Documents\diyAudio\Start Up delay.SchDoc			



Title *XEN Speaker Protection Board - DC Differential Amp*		
Size: A4	Number: 1	Revision: 2 Variant: GB1
Date: 2/03/2013	Time: 1:58:51 AM	Sheet 7 of 7
File: C:\Users\Alexis\Documents\diyAudio\Sense.SchDoc		

xen



Title *XEN Speaker Protection Board - DC Differential Amp*			xen
Size: A4	Number: 1	Revision: 2	
		Variant: GB1	
Date: 2/03/2013	Time: 1:58:51 AM	Sheet 7 of 7	
File: C:\Users\Alexis\Documents\diyAudio\Sense.SchDoc			