Using the 100-1003 Vocal Filter

I. Construction

Before you begin to build you board, please note that some of the values on the silkscreen are different from what they should be. Consult the below tables for a list of changes.

REV NC Board Reference Designator	Silkscreen Value	Real Value
R128	200	270
R174	200	270
R220	200	270
R253	100K	390K
R257	100K	390K
R290	100K	390K
R294	100K	390K
R327	100K	390K
R331	100K	390K

My recommendation for solder is Kester 331 Organic Fluxcore solder. However, any high quality rosin core flux is also suitable. The advantage of the Kester 331 is that you can clean the board up with warm water. Just keep in mind that Kester 331 is a MUST clean flux. You should not even leave it overnight as the next day will be too late, and you could have significant corrosion take place. I generally mount most of the components in the board and solder them in the same sitting. Whether the board is finished or not, it gets cleaned when I am done for the day.

If you use Rosin core flux, it will be up to you to decide whether or not to clean it and with what. I just don’t like the nasty chemicals you have to use to do this.

Now, one thing to keep in mind, when you are wiring up the front panel, NEVER use Kester 331. The 331 flux will wick up between the insulation and wire where you cannot clean it, and eventually, the wire will fain due to corrosion. Use only a high quality Rosin Core or No Clean Flux on front panel wiring.

Before you being to build the board, you will need to decide just how much of the board you wish to build. For instance, there are three control voltage shapers on the board with four breakpoints each. I have found, in general, two break points to be adequate, and you can save a bit of panel space (this eliminates a total of 12 pots). You can determine which parts to leave off the board and thus save a bit on construction.

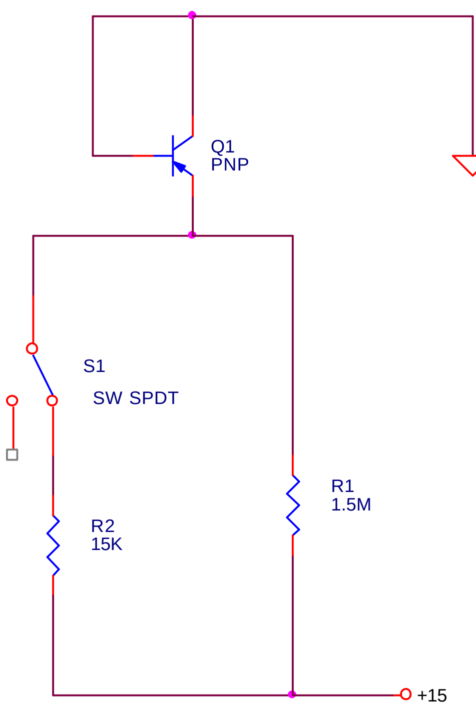
Also, there are 106 bypass caps on the board. You could probably leave some of them out, but, you are on your own if you do this. I prefer to have one bypass cap for every supply pin where practical.

Also, there are 9 CA3280's on the board. While most parts are available from Mouser or Digikey, you will have to hunt around a bit for the CA3280's. I do offer these for sale with the board. See the web page for the Vocal Filter Board for details.

It should also be noted that as of the date that this document was published, there were no circuit errors known on the board. Although, as noted above, there are some component value errors in the silkscreen. What this means is that at the moment there are no cuts or jumpers.

Transistor Matching

I use 2n3906 transistors for the exponential pairs. You should try to match these and then epoxy them together in pair. The PC board is laid out so that you can glue the flat sides together and insert them into the board. You do need to be careful when doing this, however.



This is the circuit I use for matching transistors. Q1 is the device under test. I generally build this up on a solderless breadboard strip. Several things to keep in mind, do not handle the transistors with your fingers. The heat from your fingers will throw off the measurements. Remember, you get about 2 mV/^{o}C and it doesn't take a whole lot to mess things up. Also, try to do this while the temperature is not changing much, like early evening. Also, I recommend the use of a 4 ½ digit voltmeter if you have one, however, a 3 ½ will work as well.

To make the measurements, connect the voltmeter between ground and the emitter of the transistor. You should get about -.6 volts when the 15K resistor is switched in, and less voltage when the 15K resistor is switched out. Record these voltages for each switch position for each transistor. When you are all done with a batch, you can then match up the closest candidates. What you are doing is basically matching the transistors at both high and low current. You need to match them to about 2 mV at both settings.

If you can't find matches for a few of your candidates, you might as well throw the data away, because the next time you take data, your test conditions will be different and the old data will be meaningless.

Construction Options

1. Voltage Reference.

The schematic shows an LM336 2.5 volt reference being used (U2). You also have the option of using the LM4041-ADJ reference, which is actually the one I prefer to use. It can be substituted quite easily and the schematic would look like this:

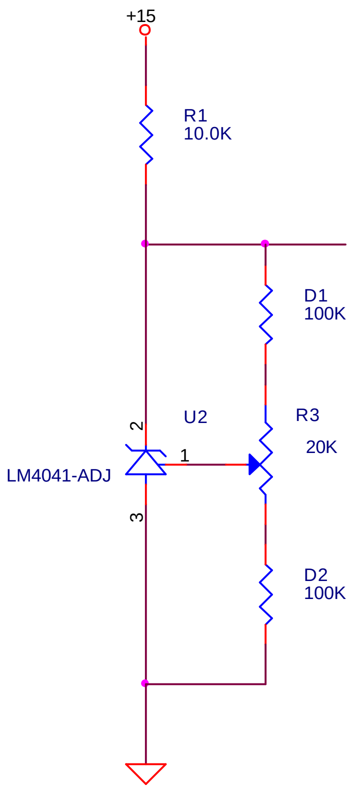


Figure 1

The LM4041-ADJ will fit exactly in the same place as the LM336 (i.e. same pin out). You do need to change the two diodes, D1 and D2 to resistors of 100K. You will still need to adjust the reference to get the + 10 volt reference to be 10.00 volts.

2. Clipping Diodes

In the voltage controlled filter sections there are a pair of 1N751 (5.1V) Zener diodes which will limit the signal swing (D21, D22 and D24, D25 and D27, D28). This is helpful, sometimes, at high resonance to keep the filter from saturating, however, this will also affect the way the filter sounds. You may, for instance, want to leave these diodes out. You may also want to change their voltage. However, going higher than 10V (1N758 or 1N5240) will pretty much be like leaving them out. You will have to judge which way sounds best to you. These diodes will have a major affect on the sound of the filter.

3. Diode Wave Shapers

There are three sets of diode wave shapers. These are what are used to control the vowel that is created by any particular control voltage. Each shaper has four breakpoints. You may feel that you don't need or want four break points, so it is possible to eliminate two of them quite easily.

If you leave out U45, U46, U50, U51 , U55, U56 and their associated components you will have three shapers with two breakpoints each. This will save a bit of space of the front panel as well (a total of 12 pots). Each shaper section will still have 6 pots (4 for the break points, plus an offset and gain pot).

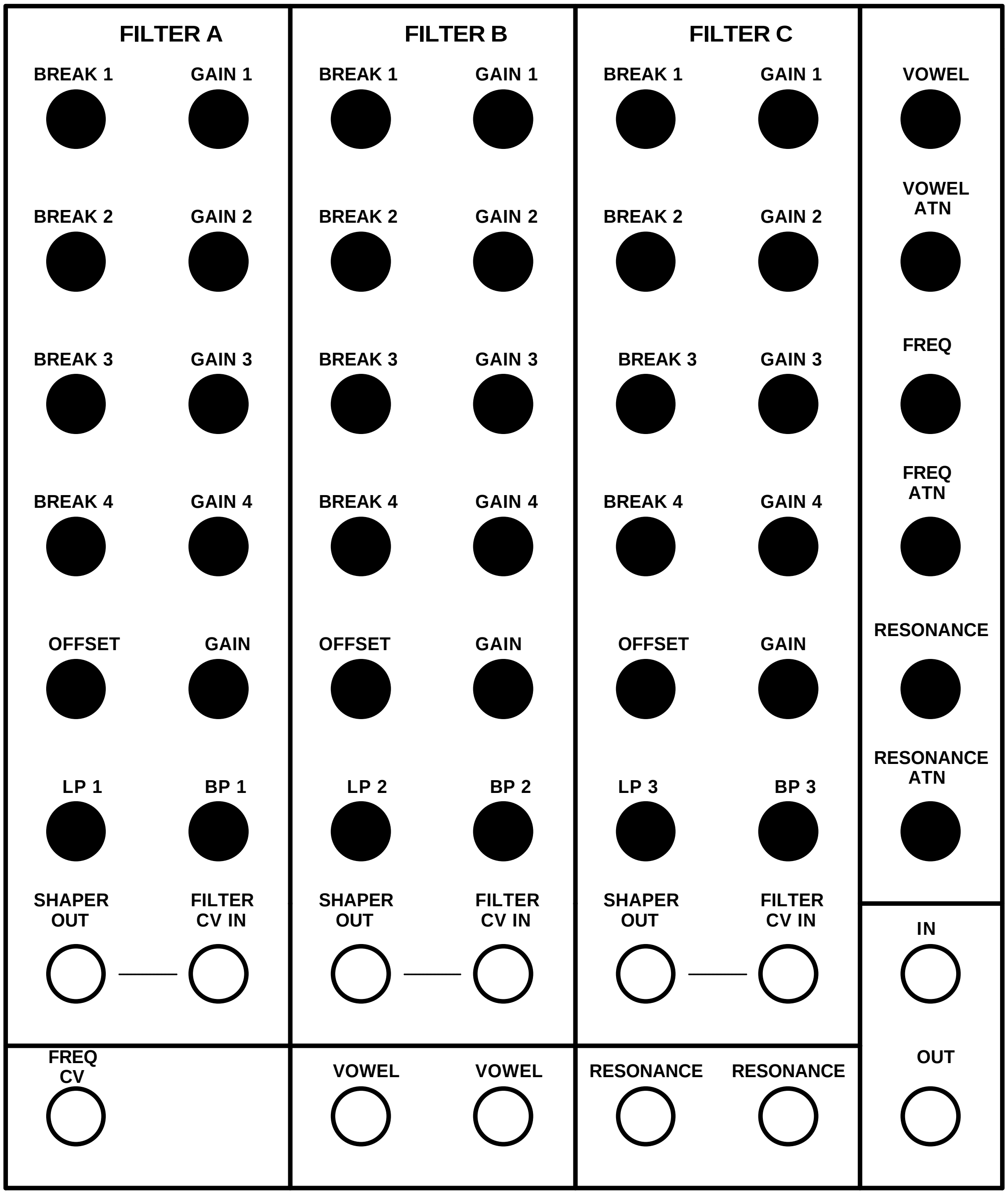
4. Front Panel

Refer to the front panel drawing and the front panel schematic, found else where in this document. One thing you will note is that the suggested front panel drawing below does not match the front panel schematic found else where. The front panel schematic reflects every possible thing you can do with the board, while the front panel drawing reflects what there is room for on the panel. As noted earlier, there are even other things you could eliminate as well, but, this is what I actually have on my front panel, and it seems to be more than adequate.

The solid black dots are knobs, the hollow circles are jacks. The jacks labeled shaper out goes into the corresponding frequency control input. I actually have the output of the shaper jack wired into the input switch of the jack, just to save three patch cords. This allows me, if I want to, to take the shaper output, process it further, and then return it back to the filter.

The Vowel ATN, Freq ATN and Resonance ATN knobs are connected to the appropriate input jacks so that the control signal can be attenuated. I use 100K pots for the attenuators, and 10K pots for the ones that just send control voltages to their inputs on the card.

The reason there is only one frequency control jack was because I didn't put enough inputs on the card…dang it all. However, one master frequency CV input should be more than plenty.



Theory of Operation

If you happen to have Electronotes, there is a fairly nice article on this type of filter in there. I wish I had had that article, as I would have made some minor changes to the features of this board, however, if you have a modular synthesizer, you can accomplish the same thing quite easily by using the vocal filter in conjunction with other modules. Electronotes 102, June 1979 has an article on what it calls a "Vocal Effects

Waveform Animator". Good reading and it may give you some ideas on additions you may want to make.

However, what this filter attempts to do is recreate the resonance's that are present in the human vocal tract that allows us to produce vowel sounds. There are four significant resonance's in the vocal tract, which can be controlled by how we shape our mouth, tongue, etc. To accomplish this electronically, we must use a voltage controlled filter. Four filters would have been a bit on the overkill side, and also much more expensive. Three seems like a good number, and that is what I use.

To control the vowels each filter has a wave shaper that is used to contour the control voltage. You can select resonant frequencies from a chart that shows the resonance's for each vowel and use the wave shapers to put out the voltages necessary to create a series of vowels for a particular series of voltages. Or, you can do what I do, just mess with the knobs until you get something that sounds cool.

You are probably not going to get anything that sounds like human speech. If you want that, you need a vocoder. However, this module can make some very expressive sounds.

Circuit Equations you probably need to know

The following equations are going to refer to the schematic for Voltage Controlled Filter 1, which is on sheet 9 of the current version of the schematic (March 31, 2003).

Filter Scale

The filter scale mostly depends upon the gain of U20B. The exact gain of U20B is going to be a little difficult to determine because there is a parameter that we have little control over that determines the gain, but, we can get within the ball park. Why this is so will be discussed a bit later.

The gain of U20B is controlled by two different things, $\mathbf{I_{ABC}}$ and $\mathbf{I_D}$. IABC is by far the easiest to deal with, so we will do that one first.

$$\mathbf{I_{ABC} = -(R138/(R141+R140)) * (V_{REF}/R145)}$$

If you substitute in values, and for the sake of argument, the value of R141+R140 is about 100K, if you consider that the pot is in the center of travel, and keep in mind that VREF = -10Volts.

$$\mathbf{I_{ABC} = -(100K/100K) * (-10V/10K) = 1mA}$$

Now, ID, on the other hand, is a bit more troublesome.

$$I_D = -(V_{BEQ6} / R121) * (R120/R128)$$

R120 = R128, and R121 = 620 ohms, so the above equation simplifies to

$$I_D = -V_{BEQ6}/620$$

Now, as you notice, there is a VBEQ6 term in there, so all we need to do is put in the value for VBEQ6. Well, it isn't that easy. This value is not very determinate.

$$I_C = I_S * e^{Q*VBE/K*T}$$

We can assume that Q/KT = 1/0.026 at room temperature, IC will be 1V/R123 = 1/2.2M = .45uA. So, now we have:

$$0.45E\text{-}6 = I_S * e^{VBE/0.026}$$

Now, if we rearrange thing just a bit.

$$0.45E\text{-}6/I_S = e^{VBE/0.026}$$

Now, take the natural log of both sides

$$\ln(0.45E\text{-}6/I_S) = V_{BE}/0.026$$

$$V_{BE} = 0.026 * \ln(0.45E\text{-}6/I_S)$$

So, now to find VBE, we only need to know what IS is. Well, this is a problem. IS is not a very well controlled parameter, plus, it doubles every 10 degrees Celsius. The value of IS is typically 10^{-14}. From this we determine that VBE can be about 0.46 volts. Since the transistor in question is a PNP, this will actually be -0.46 volts. So, now we can use the above equation for ID.

$$I_D = 0.46/620 = 740uA$$

Now we can look at the OTA. The gain of the OTA will be:

$$I_O = V_{IN} * G_M * (R_D/2)/(R125+(R_D/2))$$

Where R_D is the small signal resistance of the linearization diode, and GM is the transconductance of the OTA. The RD/2 comes about because of the input structure. (Note, this may be incorrect, this was determined empirically).

From the Intersil data sheet for the CA3280 we get the equation for the small signal resistance of the linearization diode.

RD = .07/ID

And from the Secrets of OTA paper, we get the equation for GM.

$$\mathbf{GM = 19.2 * I_{ABC}}$$

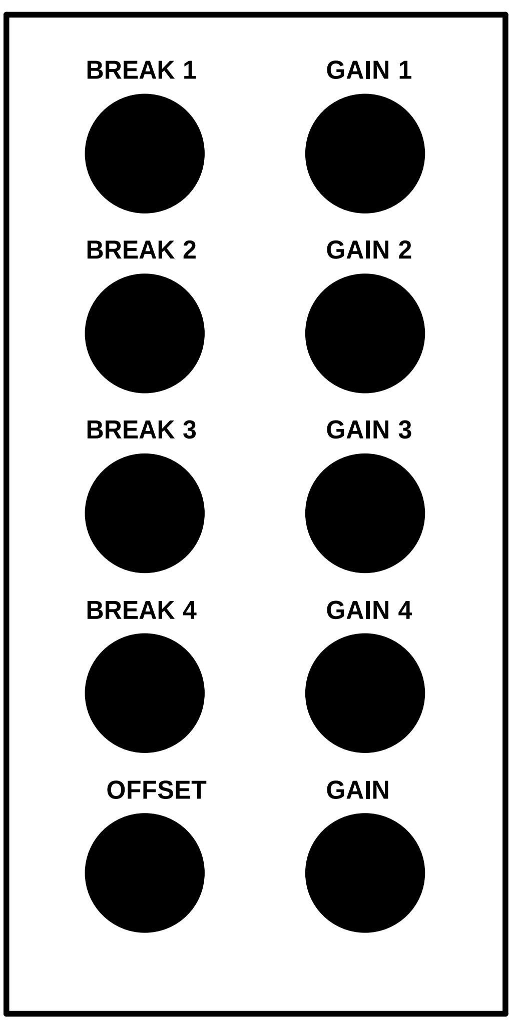
However, there is a fly in the ointment with the above equation. The CA3280 does not seem to follow this. According to the Data sheet, GM at IABC=1mA is actually 16mMHO, and not 19.2mMHO. I checked this empirically and indeed, the transconductance appears to be what it says in the data sheet. So, this will have to be verified at a later date as well.

So, now we combine all of this stuff we get the following.

$$\mathbf{I_O = V_{IN} * 0.016 * 94.6/20000 = V_{IN} * 0.000076}$$

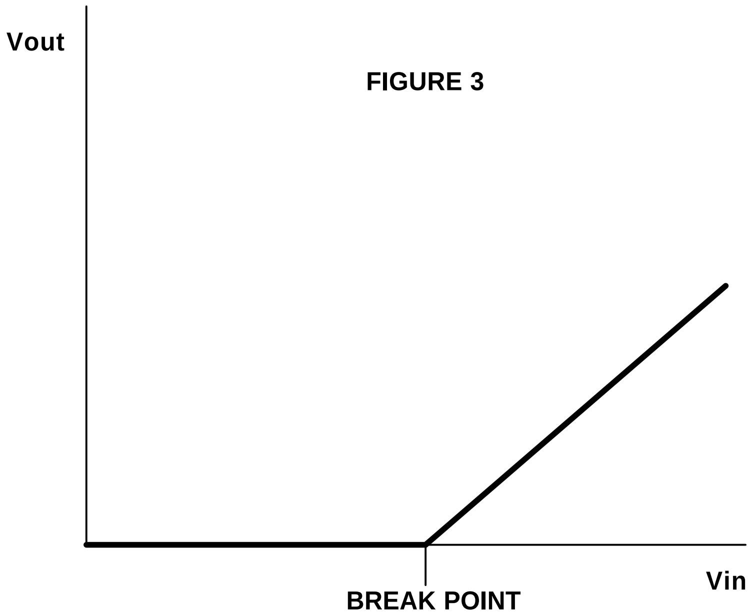
Using the above equation, the nominal resistance for R128 would be 240 ohms. Again, empirically, I have found that 270 is a better value.

USING the DIODE CONTROL VOLTAGE SHAPERS



Well, this is a dicey subject. Of all the things you need to do to use this module is learning how to deal with the control voltage shapers. Look at figure 2 below, which shows a typical layout for the front panel for one of the three shapers.

So, you can see the four break points and the four gain pots for each break point. If we just consider a single breakpoint, if we were to plot Vout vs Vin, we will get something that looks like figure 3. Changing the break point control will change the voltage where the transfer function breaks. Changing the gain control, changes how the voltage changes. Figure 3 shows what happens when the gain is positive.



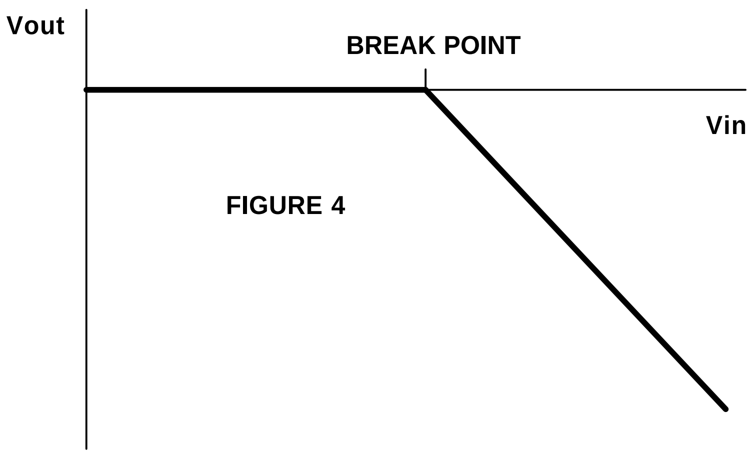
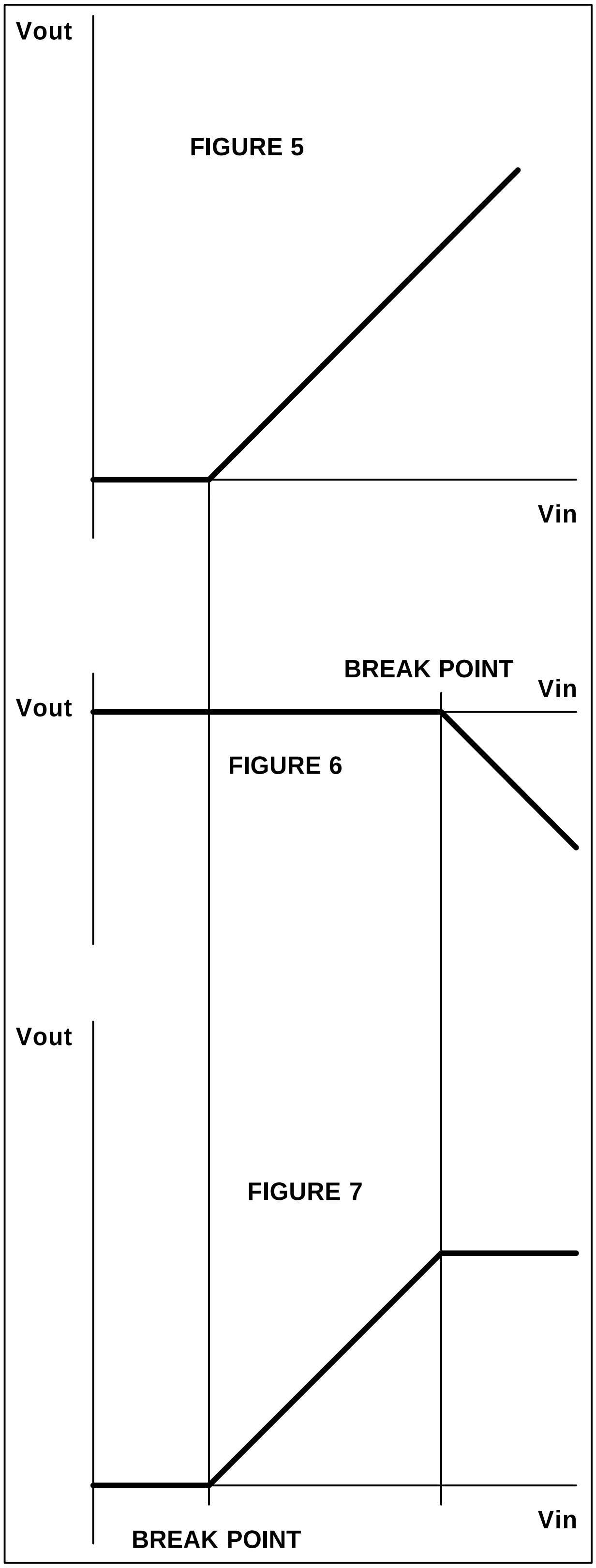


Figure 4 shows what the transfer function would look like if the gain was negative. If the gain was zero, the line would be flat, or 0 for all Vin.

Now, lets take a look at what happens when we combine two break points.



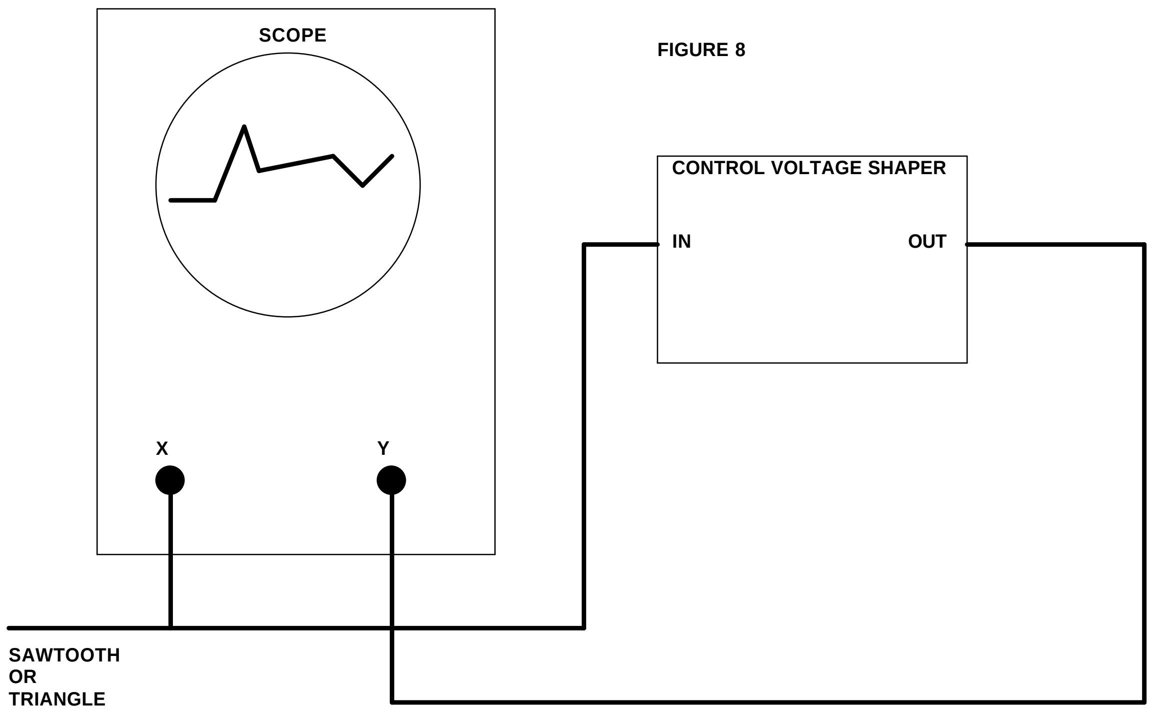
So, let us say we set BREAK1 and GAIN 1 to look like figure 5, and we set BREAK2 and GAIN2 to look like figure 6. In the actual electronics, you can not actually look at the transfer functions of individual break points, since they all get summed together before the go to the output. But knowing what is going on will help you understand what you are seeing when you look at it.

One thing we will assume is that GAIN2 is set equal and opposite to GAIN1, or, in other words, GAIN2 = - GAIN1. When you sum these two transfer functions together, the result you get is in Figure 7.

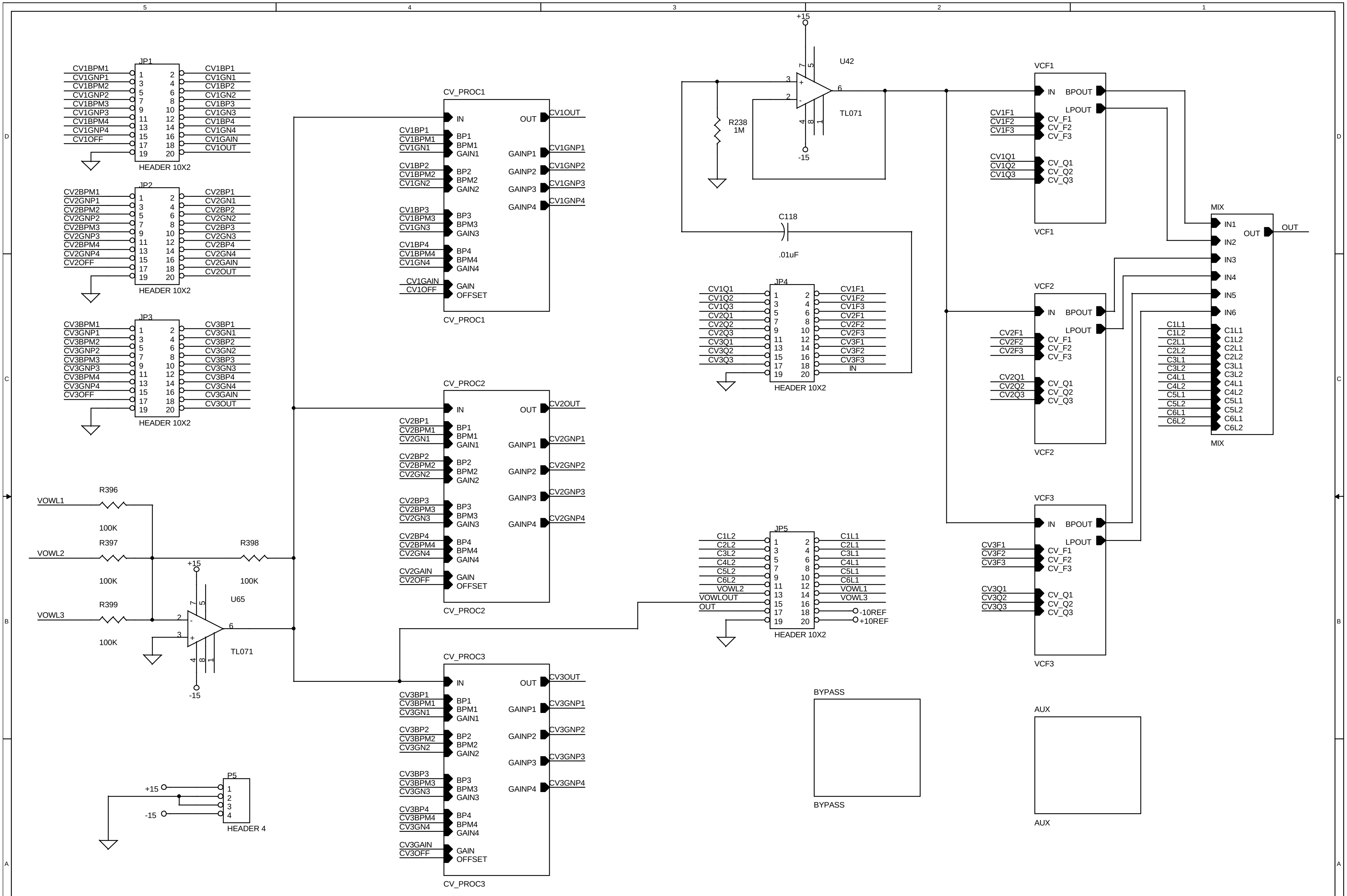
If you were to increase GAIN2 so that GAIN2 = - 2 * GAIN1, you would then see Vout decrease at the rate of –GAIN1 after the second break point.

Now, if you were in addition also have BREAK3 and BREAK4 in the mix, you can see you could begin to have some rather complex transfer functions.

Now it is time to discuss the bottom two controls, GAIN and OFFSET. These two controls are just your ordinary gain and offset controls and are quite simple, but allow you to add additional complexity to the transfer functions.



It is possible to actually see these transfer functions. If you have an oscilloscope that is capable of doing an X-Y plot, you can easily see what is going on. Consult the manual for your oscilloscope for detail on how to set your scope up. They are all different. You can use either a sawtooth or triangle wave form. It is probably best to use a wave form that goes from 0 to +10 volts if you can. Using the scope like this is highly recommended until you get the hang of the thing. I can now pretty much set it up by using my ear, although, if I was trying to do something very specific, I would probably go back to using the scope. You can also use this same technique for seeing the transfer function of a lot of other circuits.



Title
VOLCAL FILTER

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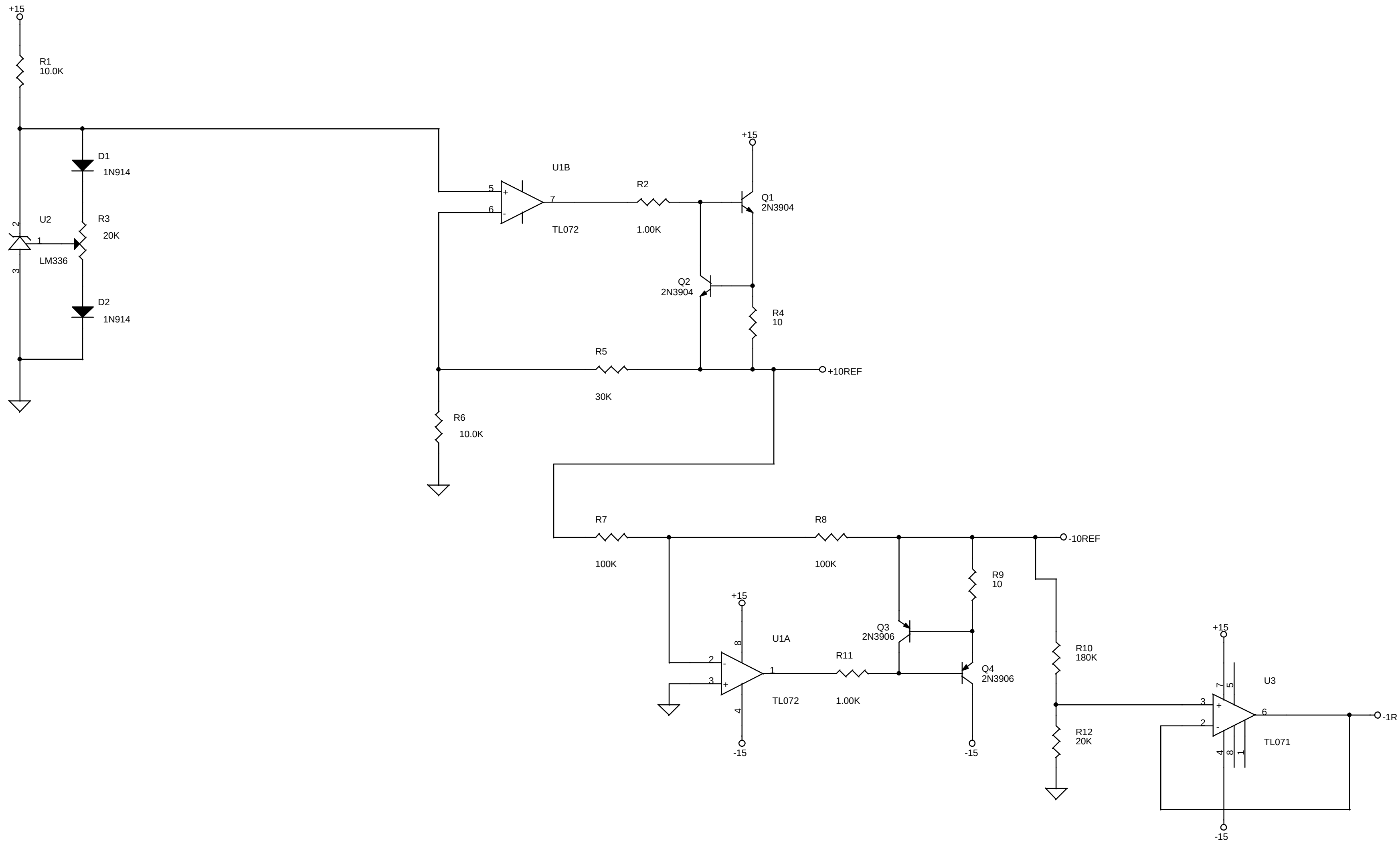

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MISC STUFF

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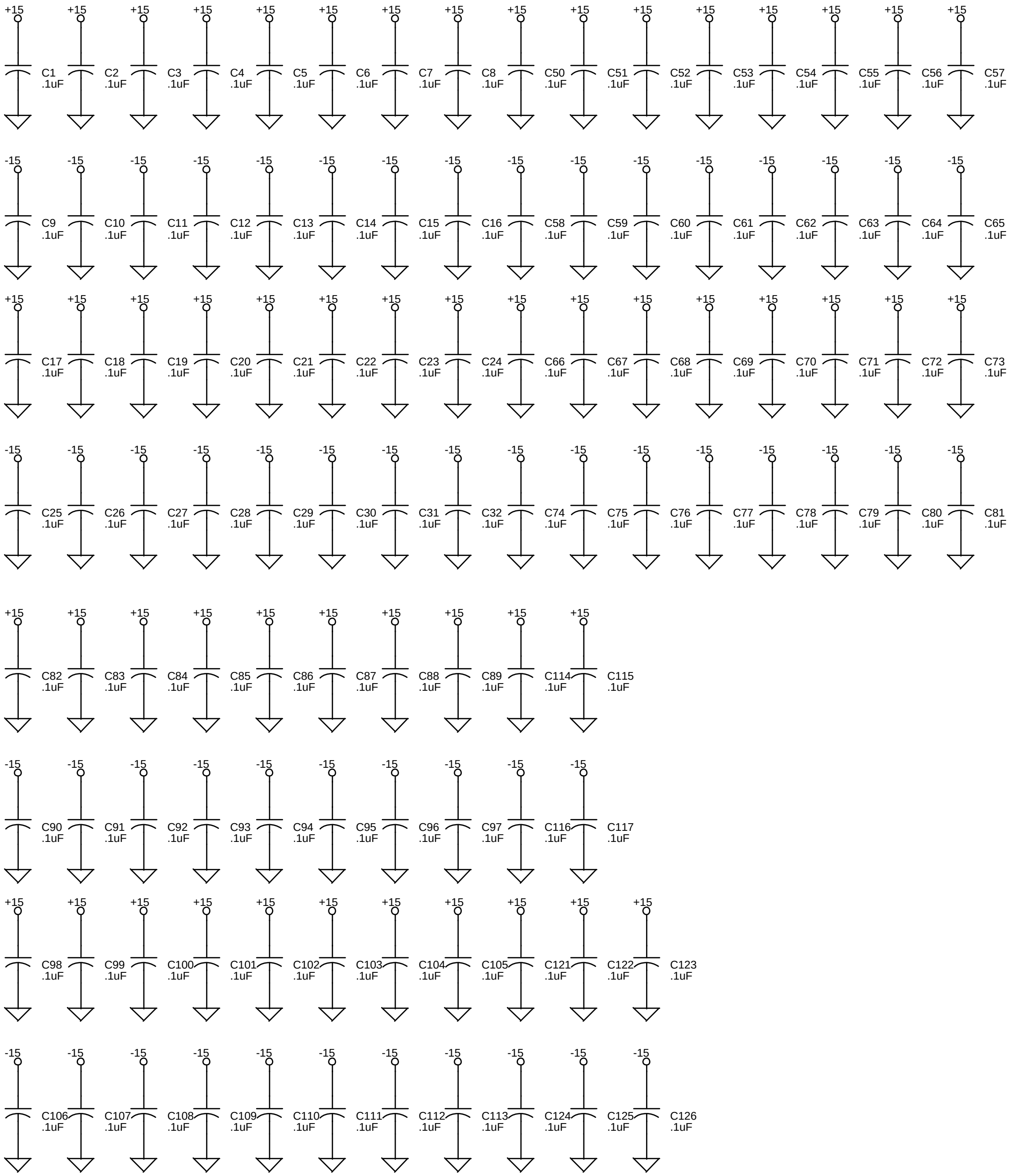

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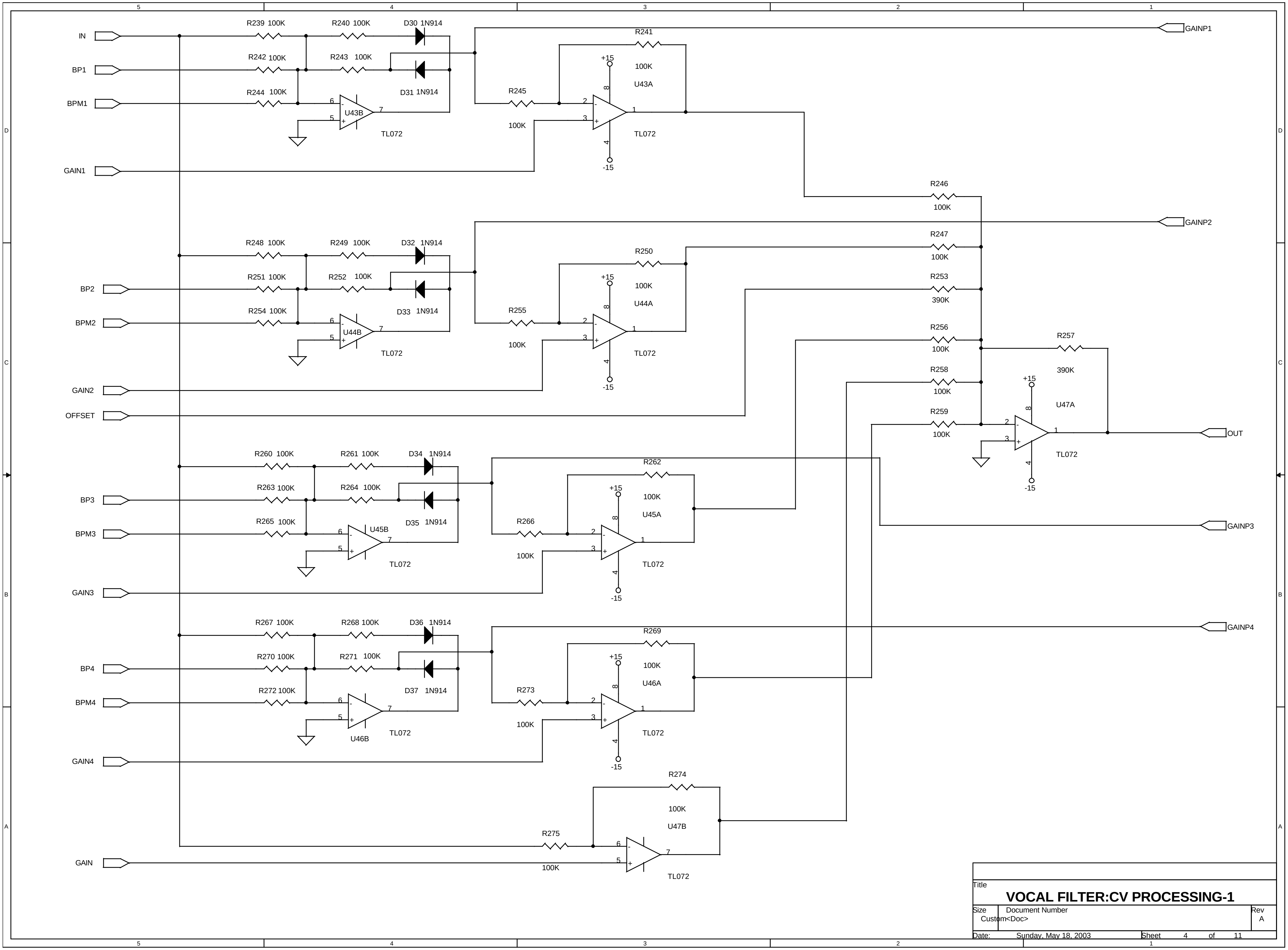
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BPM1
GAIN1
BP2
BPM2
GAIN2
OFFSET
BP3
BPM3
GAIN3
BP4
BPM4
GAIN4
GAIN
GAINP1
GAINP2
GAINP3
GAINP4
OUT
R239 100K
R240 100K
D30 1N914
R242 100K
R243 100K
D31 1N914
R244 100K
U43B
TL072
R241
100K
U43A
R245
100K
TL072
+15
-15
R246
100K
R248 100K
R249 100K
D32 1N914
R251 100K
R252 100K
D33 1N914
R254 100K
U44B
TL072
R250
100K
U44A
R255
100K
TL072
R247
100K
R253
390K
R256
100K
R257
390K
R258
100K
R259
100K
U47A
TL072
R260 100K
R261 100K
D34 1N914
R263 100K
R264 100K
D35 1N914
R265 100K
U45B
TL072
R262
100K
U45A
R266
100K
TL072
R267 100K
R268 100K
D36 1N914
R270 100K
R271 100K
D37 1N914
R272 100K
U46B
TL072
R269
100K
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R273
100K
TL072
R274
100K
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R275
100K
TL072
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Sunday, May 18, 2003
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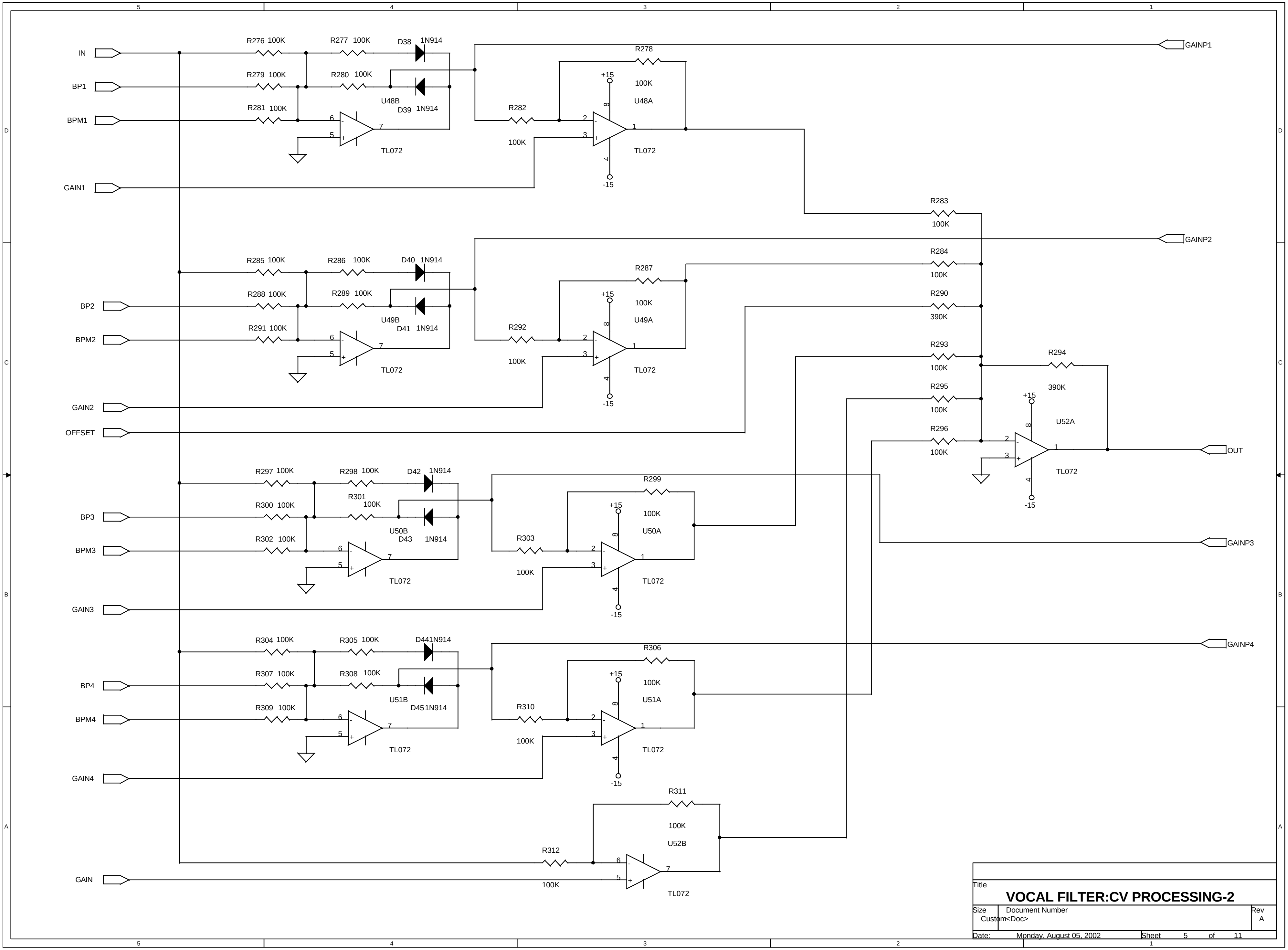
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BPM1
GAIN1
BP2
BPM2
GAIN2
OFFSET
BP3
BPM3
GAIN3
BP4
BPM4
GAIN4
GAIN
R276 100K
R277 100K
D38 1N914
R279 100K
R280 100K
R281 100K
U48B
D39 1N914
TL072
R278
100K
U48A
R282
100K
+15
-15
GAINP1
R283
100K
R285 100K
R286 100K
D40 1N914
R288 100K
R289 100K
R291 100K
U49B
D41 1N914
R287
U49A
R292
GAINP2
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R294
390K
R295
R296
U52A
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R297 100K
R298 100K
D42 1N914
R300 100K
R301
R302 100K
U50B
D43 1N914
R299
U50A
R303
GAINP3
R304 100K
R305 100K
D441N914
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U51B
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U51A
R310
GAINP4
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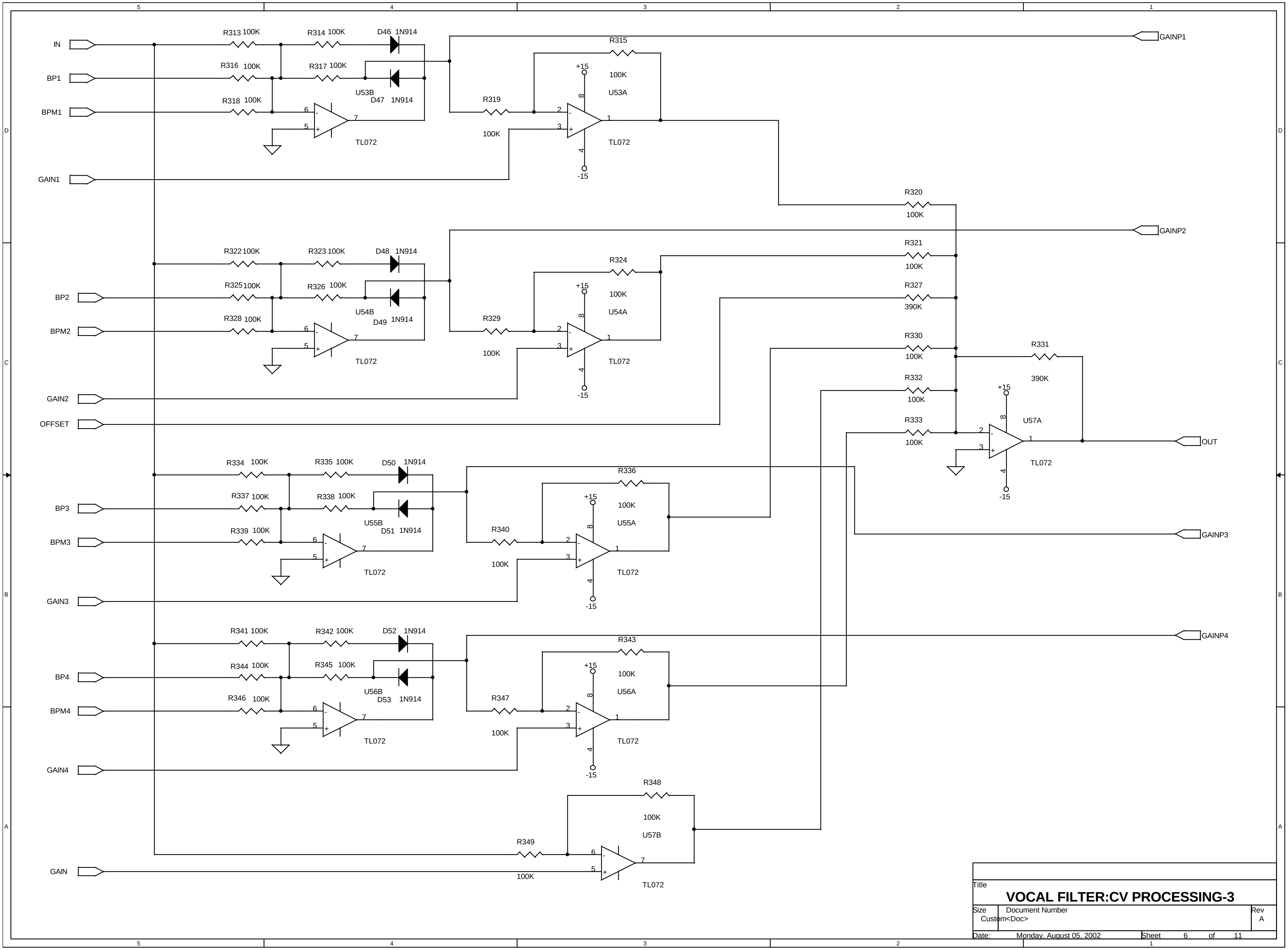
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GAIN1
BP2
BPM2
GAIN2
OFFSET
BP3
BPM3
GAIN3
BP4
BPM4
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GAINP1
GAINP2
GAINP3
GAINP4
OUT
R313 100K
R314 100K
D46 1N914
R316 100K
R317 100K
R318 100K
U53B
D47 1N914
TL072
R315
100K
U53A
R319
100K
+15
-15
R320
100K
R322 100K
R323 100K
D48 1N914
R325 100K
R326 100K
R328 100K
U54B
D49 1N914
R324
100K
U54A
R329
100K
R321
100K
R327
390K
R330
100K
R331
390K
R332
100K
R333
100K
U57A
R334 100K
R335 100K
D50 1N914
R337 100K
R338 100K
R339 100K
U55B
D51 1N914
R336
100K
U55A
R340
100K
R341 100K
R342 100K
D52 1N914
R344 100K
R345 100K
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100K
U56A
R347
100K
R348
100K
U57B
R349
100K
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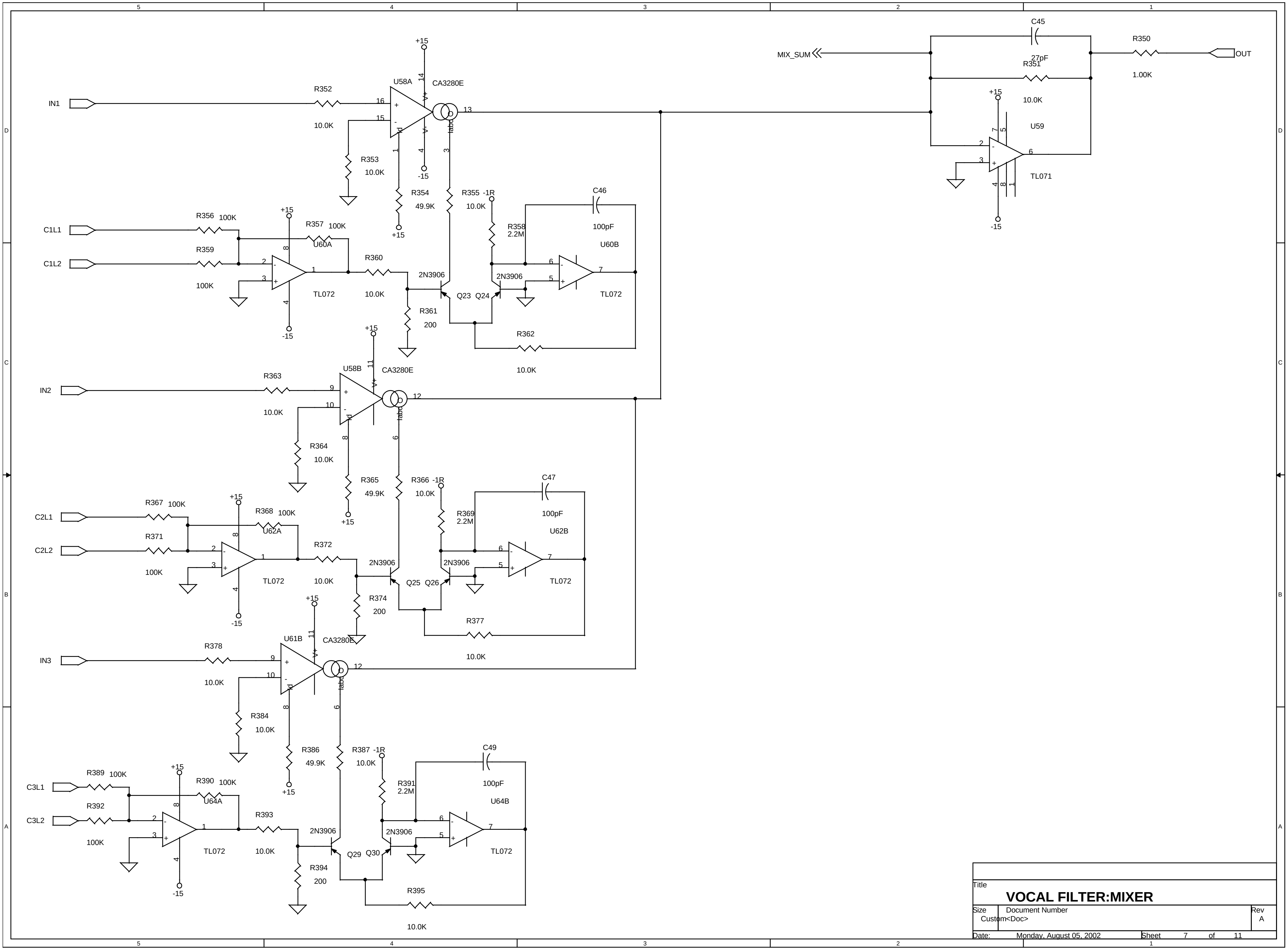

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VOCAL FILTER:MIXER

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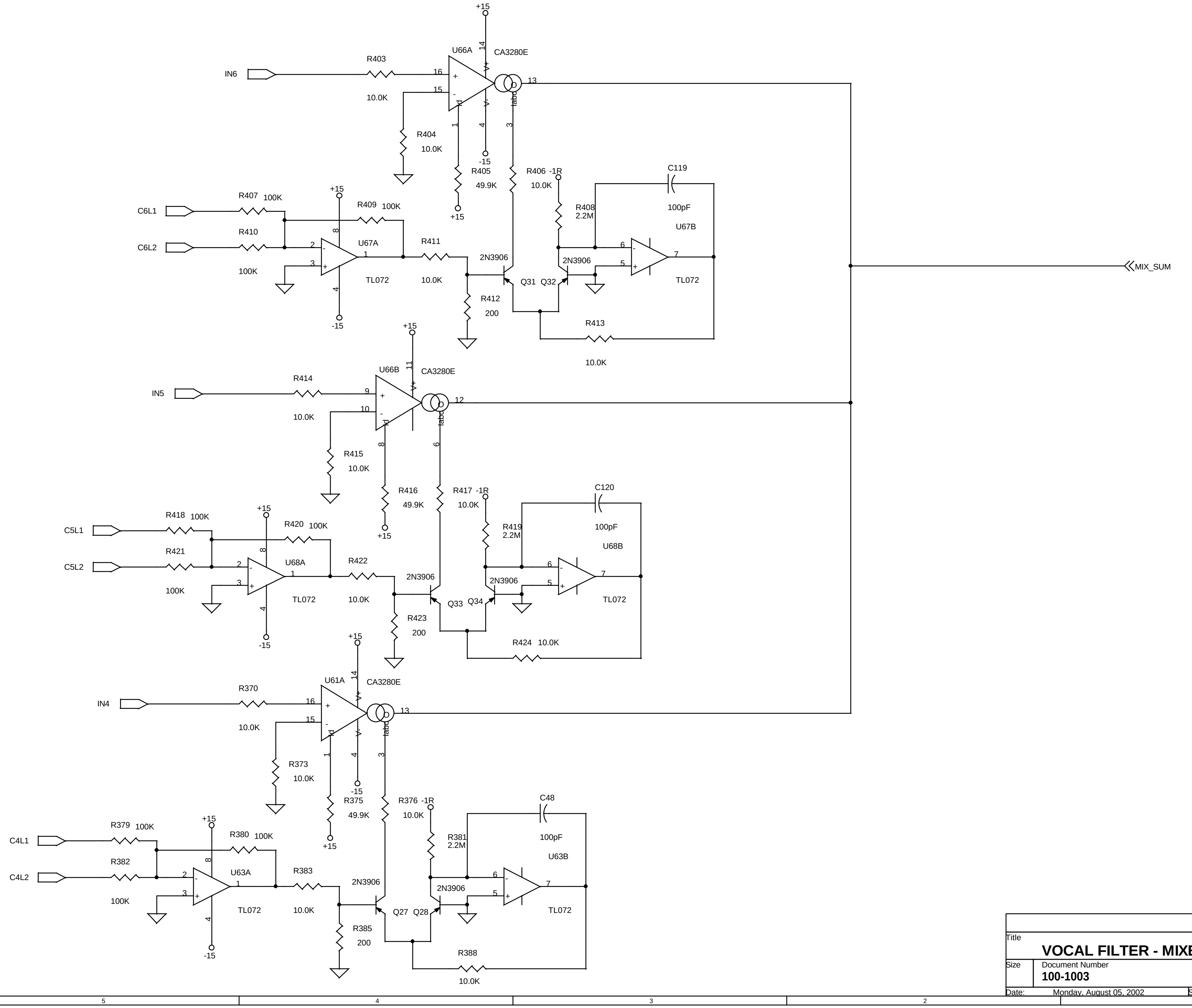

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VOCAL FILTER - MIXER

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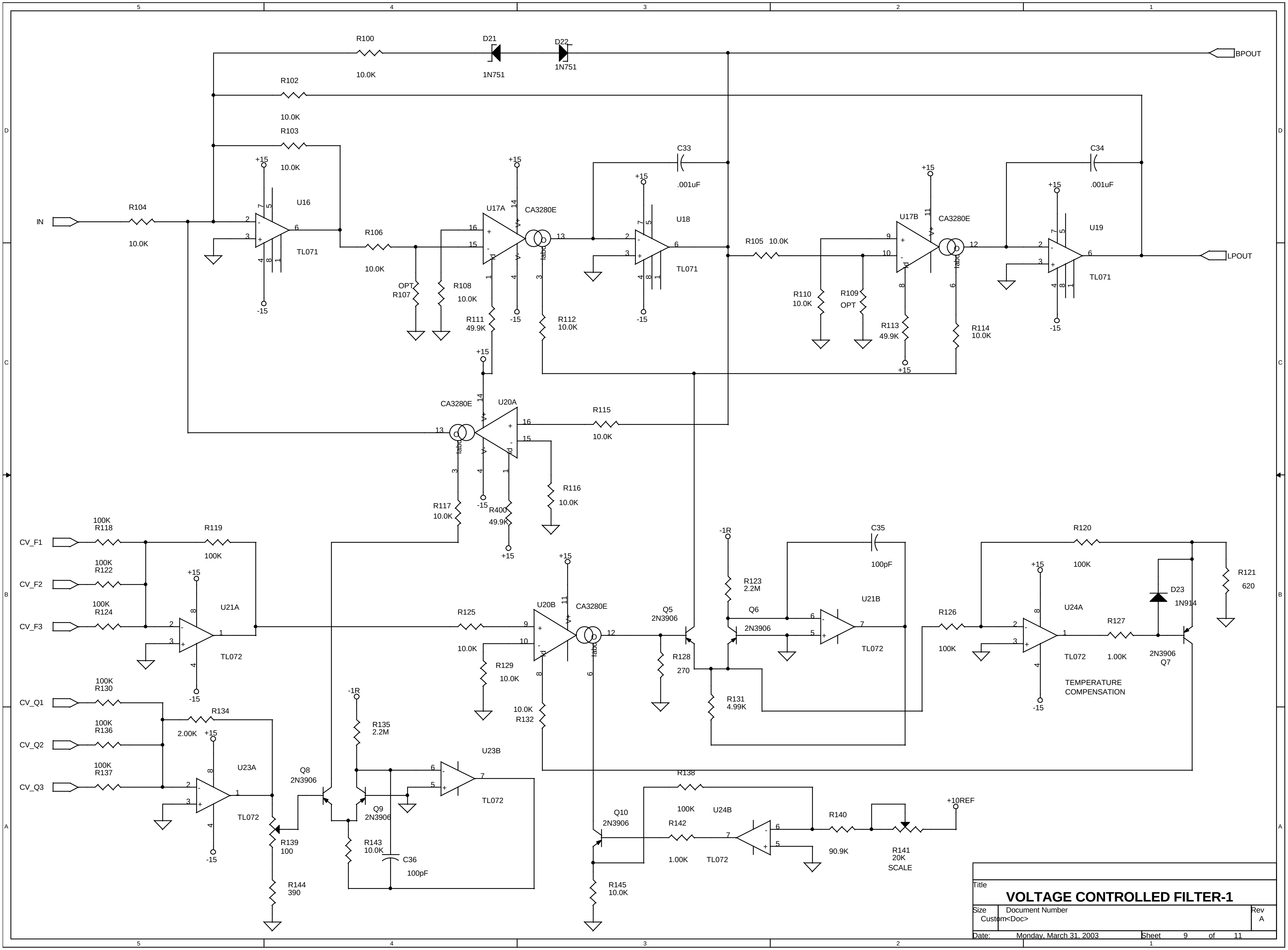

BPOUT
LPOUT
IN
R100 10.0K
D21 1N751
D22 1N751
R102 10.0K
R103 10.0K
R104 10.0K
U16 TL071
R106 10.0K
U17A CA3280E
OPT R107
R108 10.0K
R111 49.9K
R112 10.0K
C33 .001uF
U18 TL071
R105 10.0K
U17B CA3280E
R110 10.0K
R109 OPT
R113 49.9K
R114 10.0K
C34 .001uF
U19 TL071
CA3280E U20A
R115 10.0K
R116 10.0K
R117 10.0K
R400 49.9K
CV_F1
CV_F2
CV_F3
100K R118
100K R122
100K R124
R119 100K
U21A TL072
R125 10.0K
U20B CA3280E
R129 10.0K
10.0K R132
Q5 2N3906
R128 270
R123 2.2M
Q6 2N3906
R131 4.99K
C35 100pF
U21B TL072
R126 100K
U24A TL072
R120 100K
R121 620
D23 1N914
R127 1.00K
2N3906 Q7
TEMPERATURE COMPENSATION
CV_Q1
CV_Q2
CV_Q3
100K R130
100K R136
100K R137
R134 2.00K
U23A TL072
R139 100
R144 390
Q8 2N3906
Q9 2N3906
R135 2.2M
R143 10.0K
C36 100pF
U23B TL072
Q10 2N3906
R145 10.0K
R138 100K
U24B TL072
R142 1.00K
R140 90.9K
R141 20K SCALE
+10REF
Title
VOLTAGE CONTROLLED FILTER-1
Size Custom
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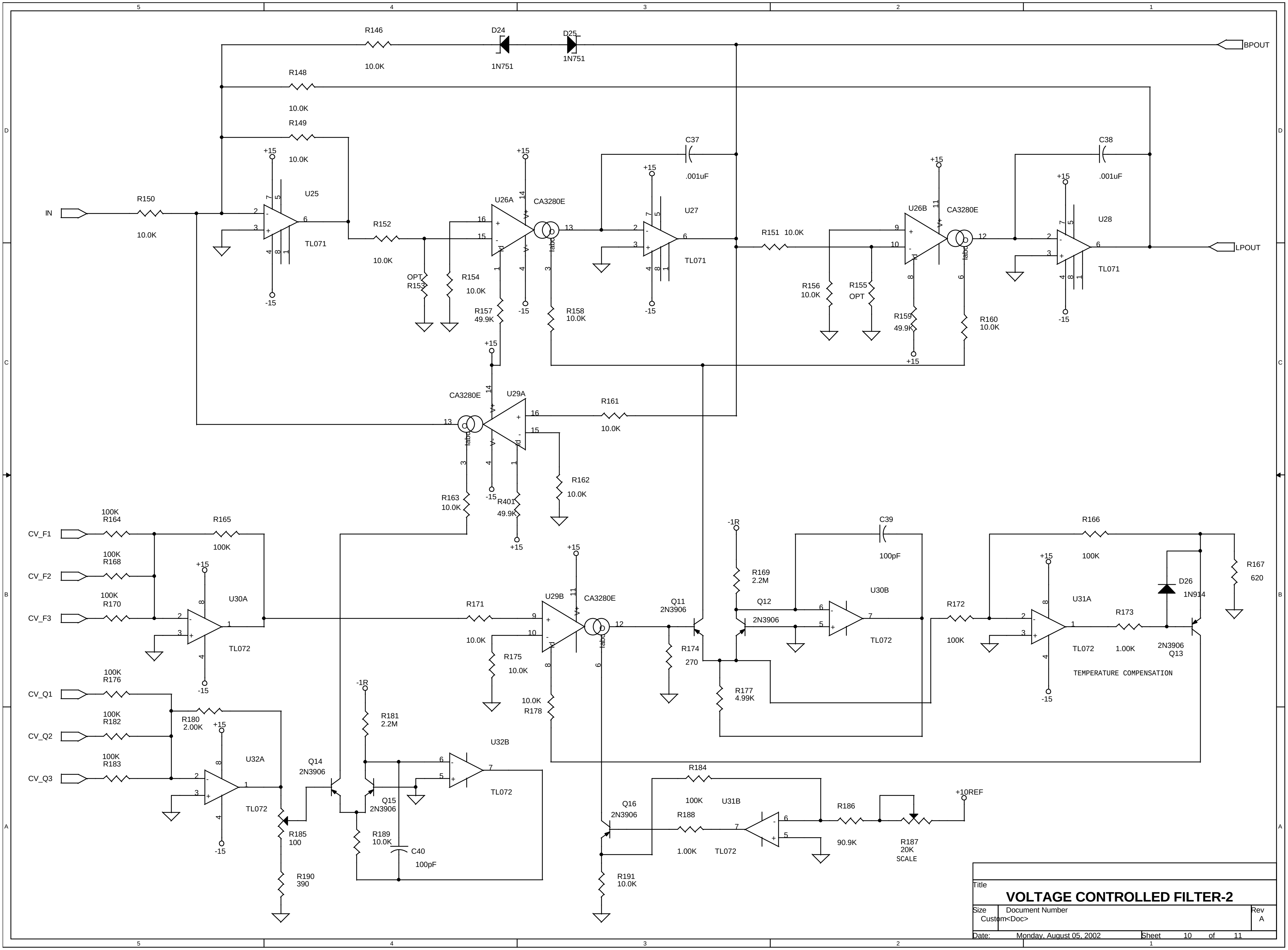
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Title
Size
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Document Number
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Rev
A
Date: Monday, August 05, 2002
Sheet 10 of 11
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LPOUT
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CV_F3
CV_Q1
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CV_Q3
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D24 1N751
D25 1N751
R148 10.0K
R149 10.0K
R150 10.0K
U25 TL071
R152 10.0K
OPT R153
R154 10.0K
U26A CA3280E
R157 49.9K
R158 10.0K
C37 .001uF
U27 TL071
R151 10.0K
R156 10.0K
R155 OPT
U26B CA3280E
R159 49.9K
R160 10.0K
C38 .001uF
U28 TL071
U29A CA3280E
R161 10.0K
R162 10.0K
R163 10.0K
R401 49.9K
R164 100K
R165 100K
R168 100K
R170 100K
U30A TL072
R171 10.0K
U29B CA3280E
R175 10.0K
R178 10.0K
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R174 270
R169 2.2M
Q12 2N3906
C39 100pF
U30B TL072
R177 4.99K
R166 100K
R167 620
R172 100K
U31A TL072
R173 1.00K
D26 1N914
Q13 2N3906
TEMPERATURE COMPENSATION
R176 100K
R180 2.00K
R182 100K
R183 100K
U32A TL072
R185 100
R190 390
Q14 2N3906
Q15 2N3906
R181 2.2M
R189 10.0K
C40 100pF
U32B TL072
Q16 2N3906
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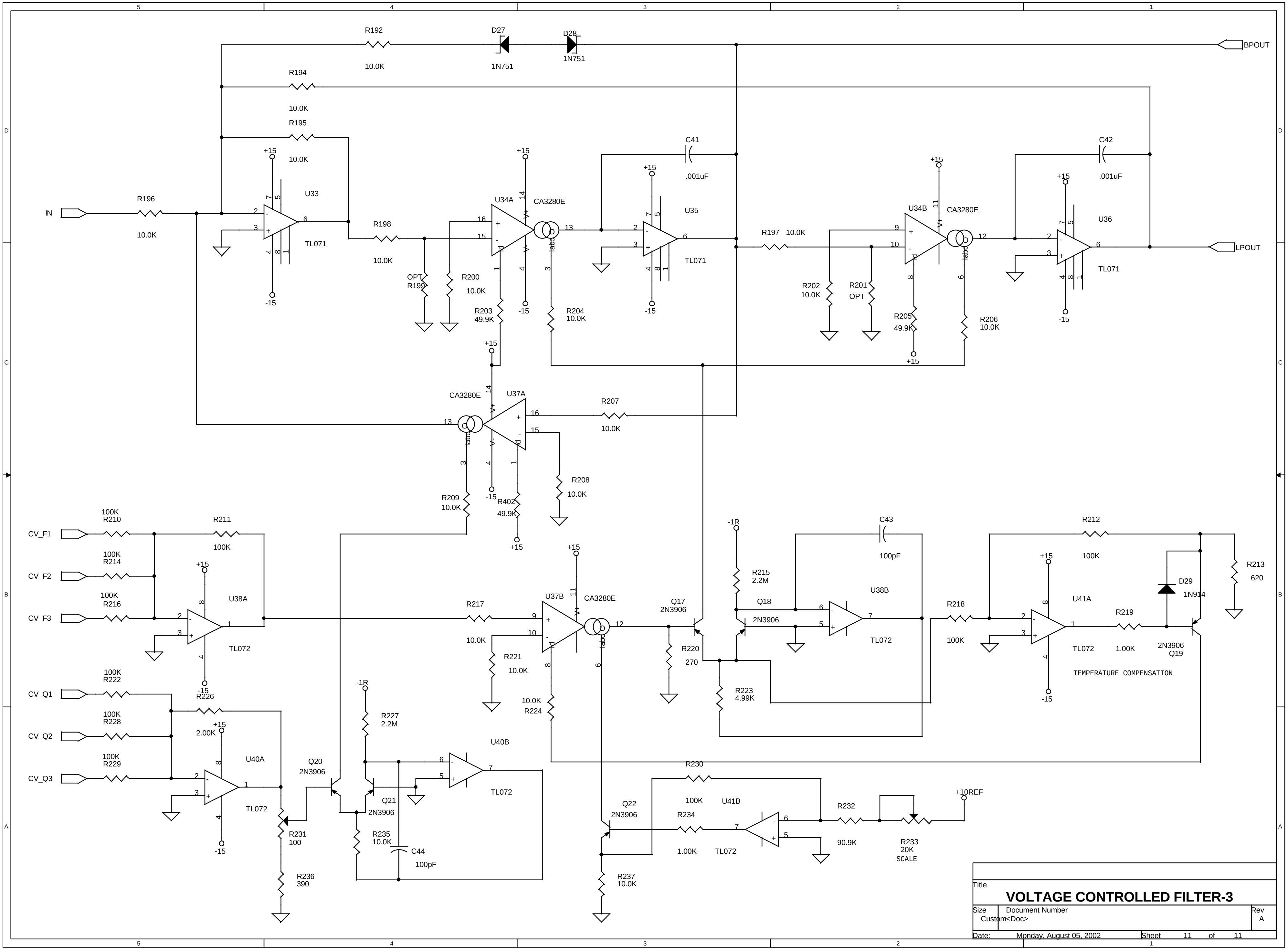
-1R



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+15
-15
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TL071
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10.0K
OPT
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R200
10.0K
U34A
CA3280E
R203
49.9K
R204
10.0K
C41
.001uF
U35
TL071
R197
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R202
10.0K
R201
OPT
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CA3280E
R205
49.9K
R206
10.0K
C42
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TL071
LPOUT
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CA3280E
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R208
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R402
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CV_F2
CV_F3
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100K
R214
100K
R216
R211
100K
U38A
TL072
R217
10.0K
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CA3280E
R221
10.0K
R224
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2N3906
R220
270
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R215
2.2M
Q18
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C43
100pF
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R213
620
D29
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Q19
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CV_Q2
CV_Q3
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VOLTAGE CONTROLLED FILTER-3
Size
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A
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Monday, August 05, 2002
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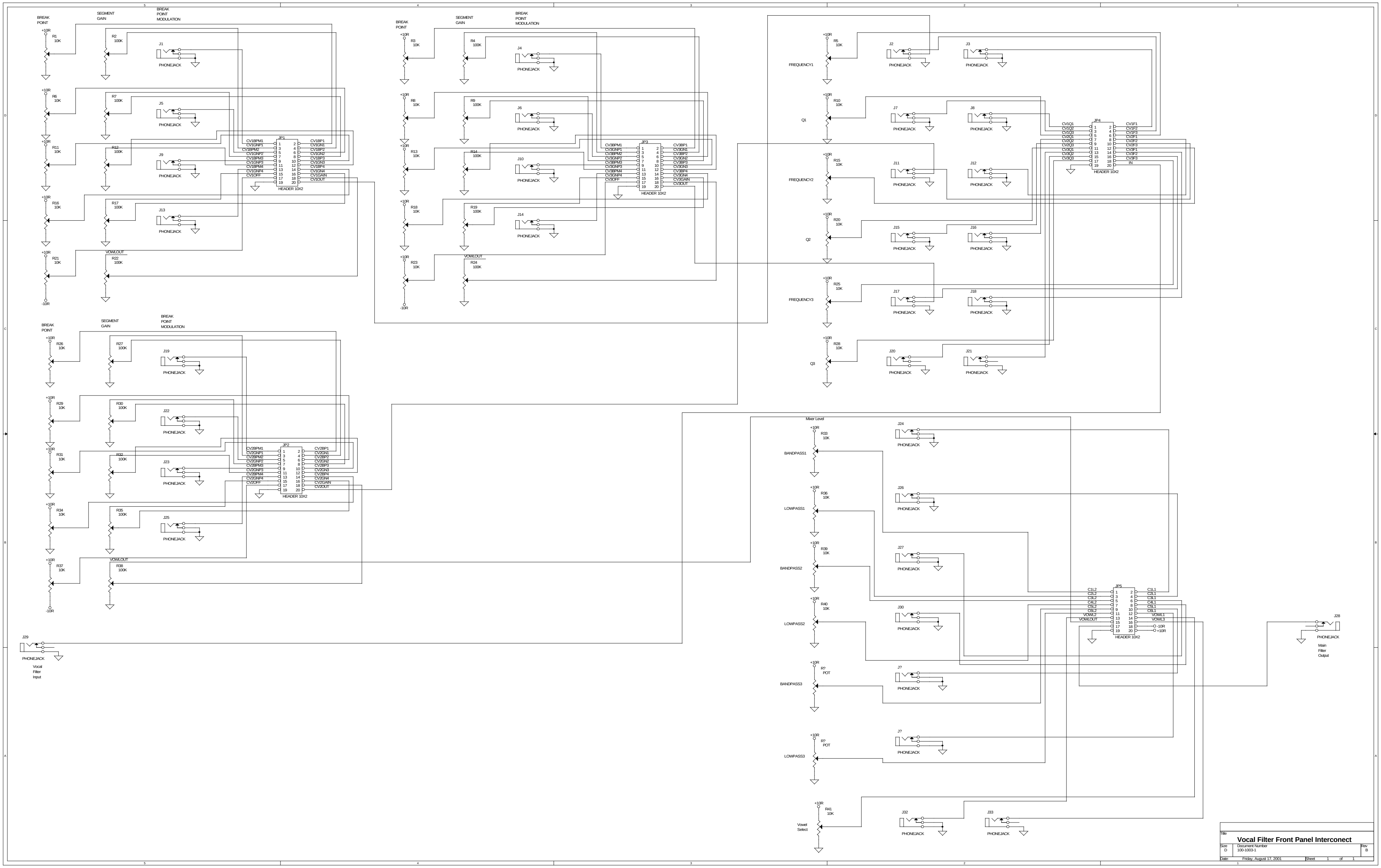
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SEGMENT GAIN
BREAK POINT MODULATION
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Q3
Mixer Level
BANDPASS1
LOWPASS1
BANDPASS2
LOWPASS2
BANDPASS3
LOWPASS3
Vowel Select
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Title
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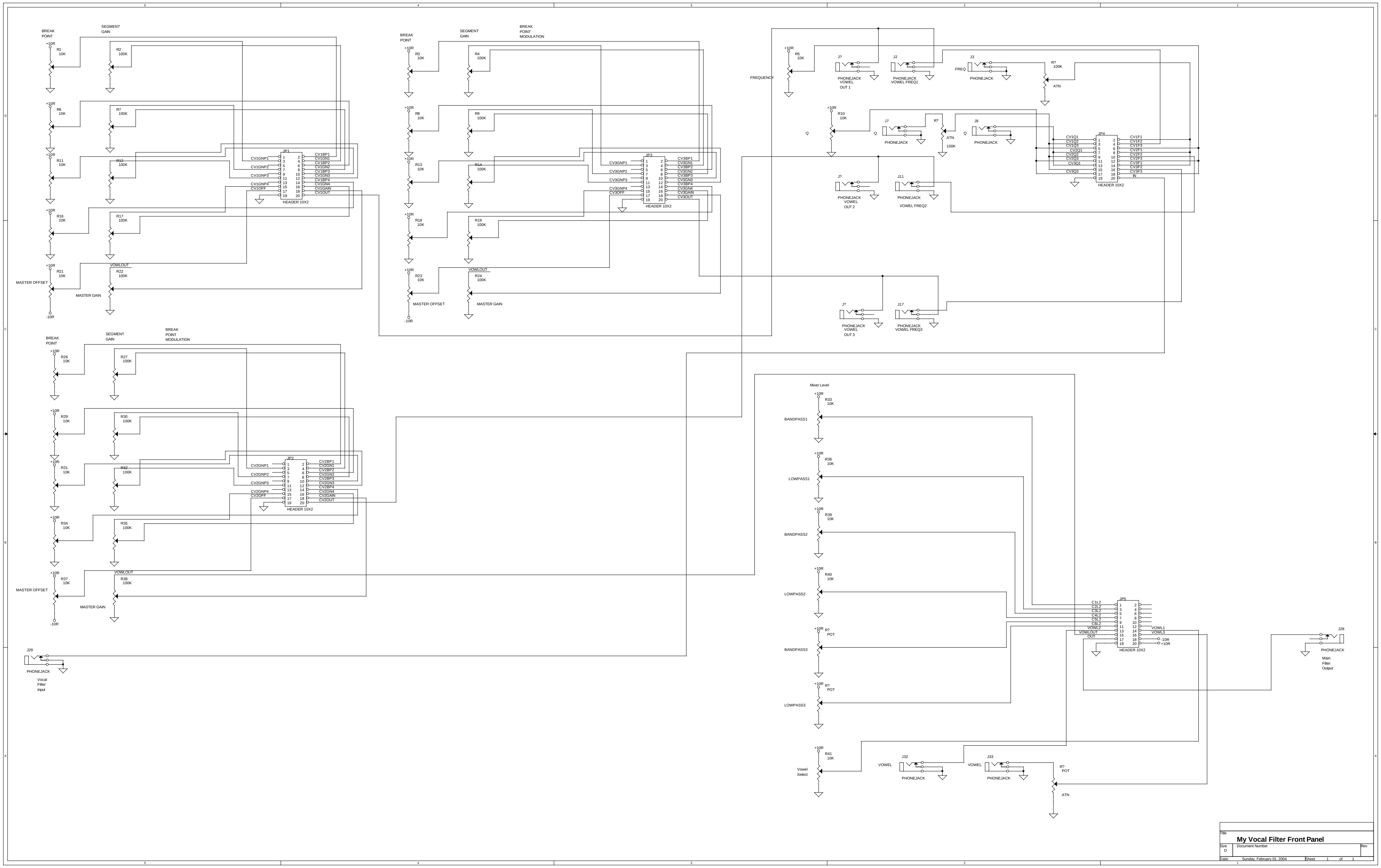
Rev B
Date Friday, August 17, 2001
Sheet 1 of 1



BREAK POINT
SEGMENT GAIN
BREAK POINT MODULATION
MASTER OFFSET
MASTER GAIN
VOWLOUT
HEADER 10X2
FREQUENCY
FREQ
Q
ATN
PHONEJACK
PHONEJACK VOWEL OUT 1
PHONEJACK VOWEL FREQ1
PHONEJACK VOWEL OUT 2
VOWEL FREQ2
PHONEJACK VOWEL OUT 3
PHONEJACK VOWEL FREQ3
Mixer Level
BANDPASS1
LOWPASS1
BANDPASS2
LOWPASS2
BANDPASS3
LOWPASS3
Vowel Select
VOWEL
Vocal Filter Input
Main Filter Output
Title
My Vocal Filter Front Panel
Size D
Document Number
Rev
Date Sunday, February 01, 2004
Sheet 1 of 1

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VOLCAL FILTER  Revised: Monday, August 05, 2002
100-1003          Revision: A

Jim Patchell
patchell@silcom.com

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Item    Quantity    Reference   Part    Mouser Part Number
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1   106 C1,C2,C3,C4,C5,C6,C7,C8,    .1uF    80-C410C104M5U
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2   6   C33,C34,C37,C38,C41,C42 .001uF  23PS210
3   12  C35,C36,C39,C40,C43,C44,    100pF   140-50P2-101K
        C46,C47,C48,C49,C119,
        C120
4   1   C45 27pF    140-50N2-270J
5   1   C118    .01uF   23PS310
6   29  D1,D2,D23,D26,D29,D30,  1N914   78-1N914
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9   1   P5  HEADER 4    538-26-48-1245
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19  1   R12 20K 271-20K
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23  12  R123,R135,R169,R181,R215,   2.2M    271-2.2M
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24  3   R128,R174,R220  270 271-270
25  3   R131,R177,R223  4.99K   271-4.99K
26  3   R134,R180,R226  2.00K   271-2K
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29  3   R144,R190,R236  390 271-390
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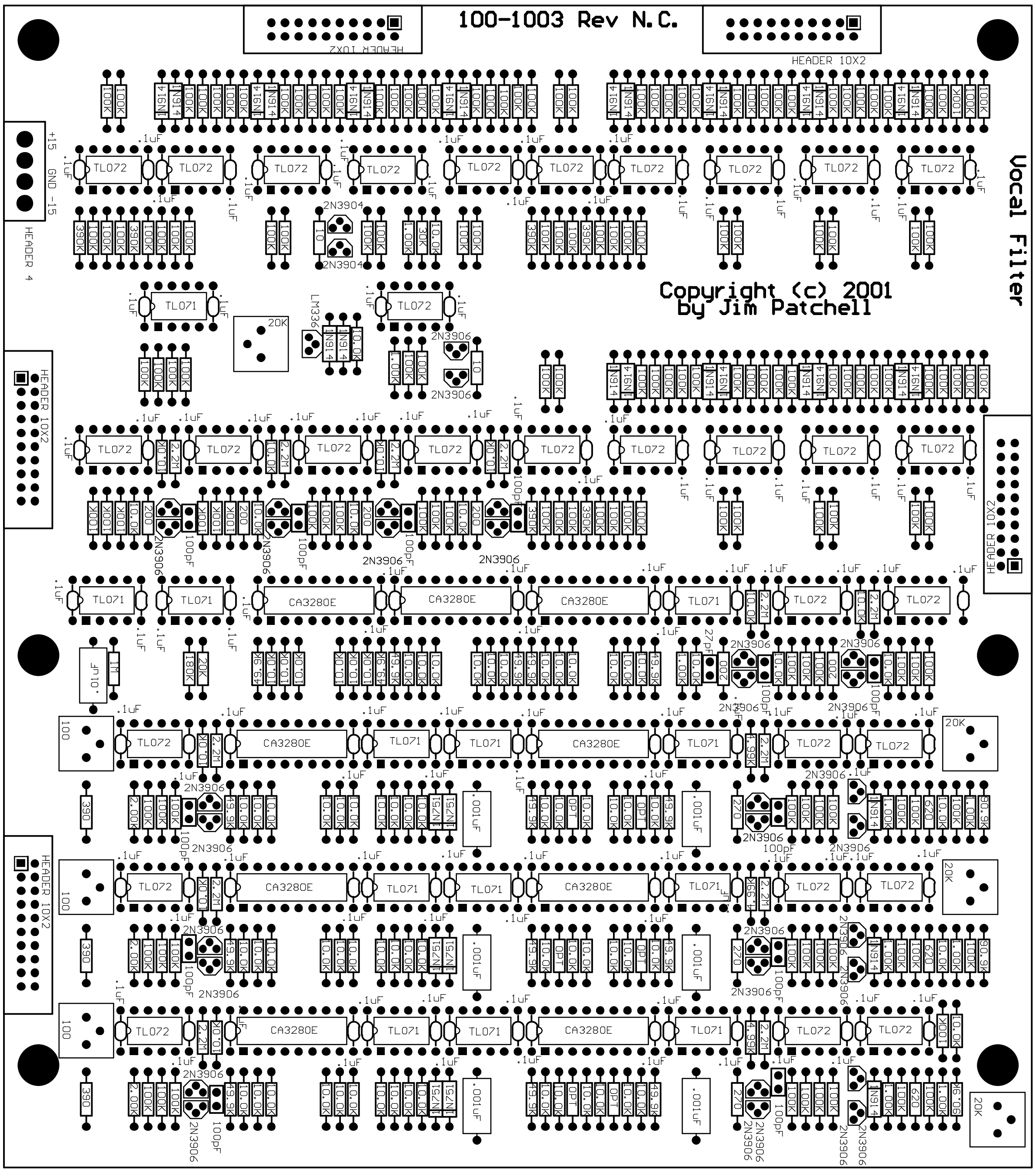

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