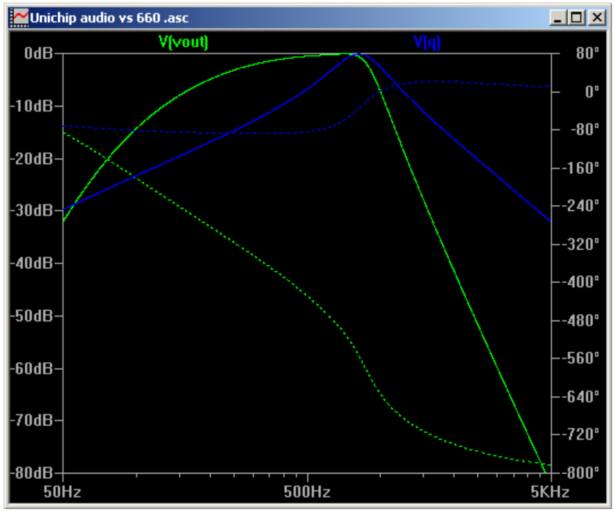
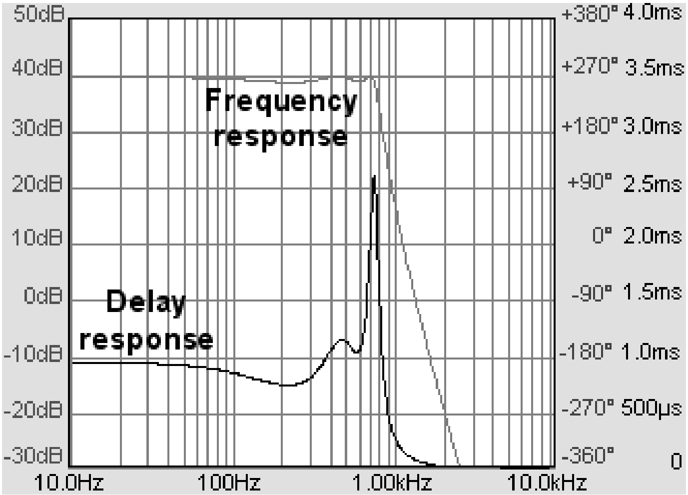
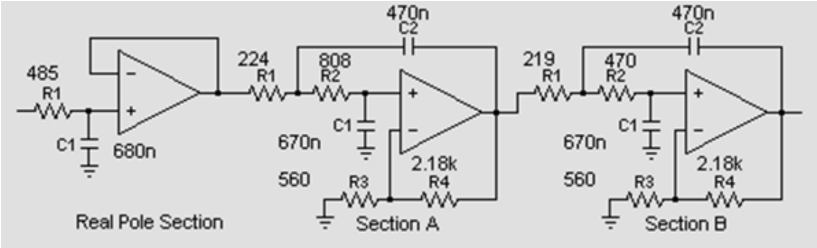
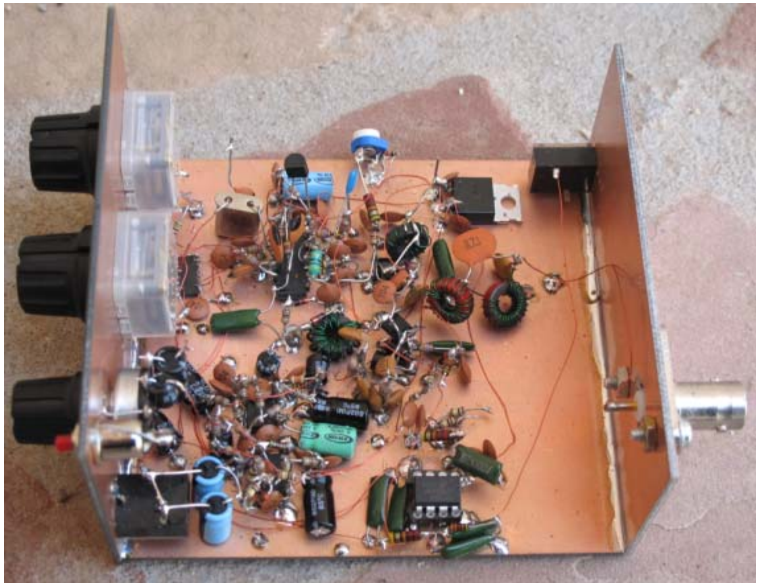




Active R/C Filter Design *and* 80M Unichip Plus DC XCVR





Dan Tayloe, N7VE

Ft.Tuthill, Az July 31, 2009

Topics

- R/C active filters
  - Use in receivers
  - Effect of Q on ringing
  - Effect of resistor values on noise
  - Distributed gain in multi-stage active R/C filters
- Three cw filters examples
  - Common parts values use
  - Minimum number of unique parts

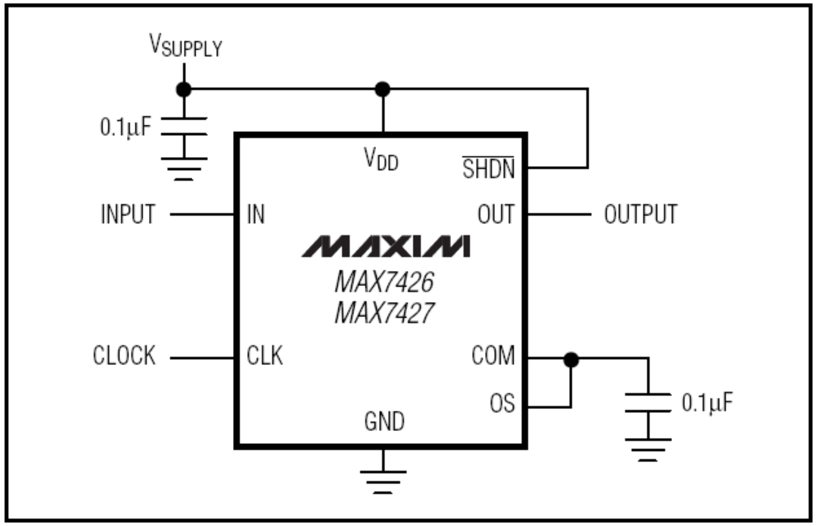
Topics

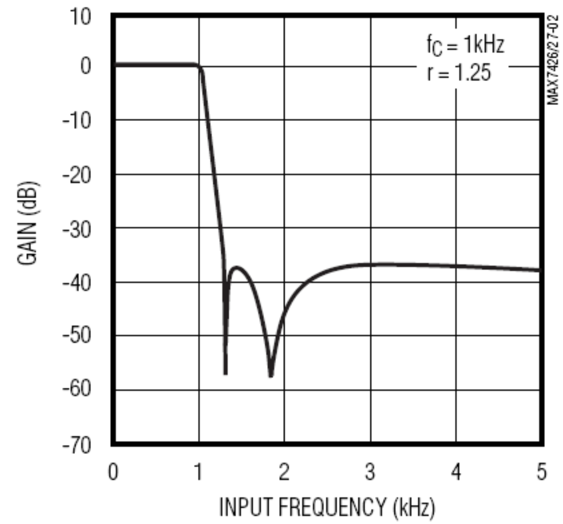
- 80m Transceiver, Unichip “Plus”
  - Update of a simple VXO controlled, DC transceiver design
  - Uses R/C filters from above
  - Goals
    - Low cost, minimum number of unique parts
    - Good receiver audio filtering
    - Modern refresh to a classic design

Audio Filter Types

- L/C audio filters
  - Pro: Excellent for very low noise applications
  - Con: AC hum pick up + inductor cost
  - Con: Large and bulky or small and high loss
- SCAF (Switched Capacitor Audio Filter)
  - Pro: Compact, Cheap ($1-$2 ICs)
  - Pro: Sharp roll off, change cutoff frequency simply by changing clock frequency
  - Con: Noisy! Used at end of the audio chain
- R/C Active filters
  - Pro: Excellent for very low noise applications (receivers!)
  - Pro: Very large dynamic range (very small to very large signals)
  - Con: Relatively high parts count for good filters
  - Con: Tends to be fixed frequency cutoff

Dead simple SCAF circuit





- Fixed frequency SCAF using a MAX7426 requires only a fixed cap on the “clock” (~180 pf = 1 KHz)
- Simple, effective, sharp 40 dB cutoff
- Just need to AC couple inputs and outputs (0.1 uf)
- Need unity gain audio amp to drive headphones

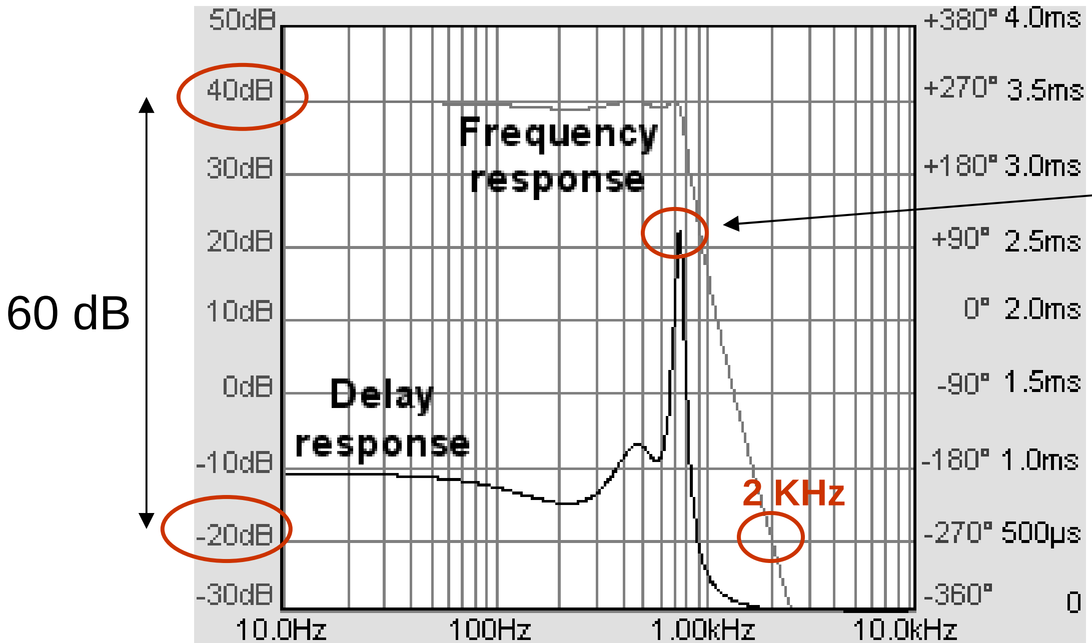
Active R/C Design Topics

- Effect of Q on ringing
- Effect of resistor values on noise
- Distributed gain in multi-stage active R/C filters

Audio Filter Q Implications

- An R/C filter is (normally) composed of multiple one or two pole filter stages
- Each stage has a “Q”
- The higher the Q, the faster the steeper the frequency roll off
- Steeper frequency roll offs gets rid of QRM more quickly
- High Q in a filter is a good thing, right?

Audio Filter Q Implications



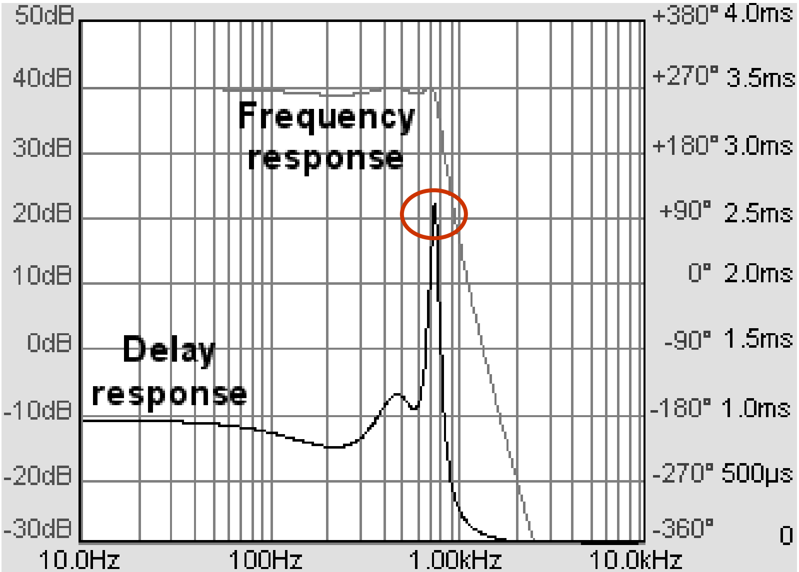
Note the very sharp delay spike at the cutoff frequency

Characteristic of high Q filters

Q = 5 here

- Example: 5th order Chebychev
  - 1 dB Ripple near cut off
  - 40 db total filter gain
  - 800 Hz cut off frequency
  - 60 dB of gain reduction at 2 KHz

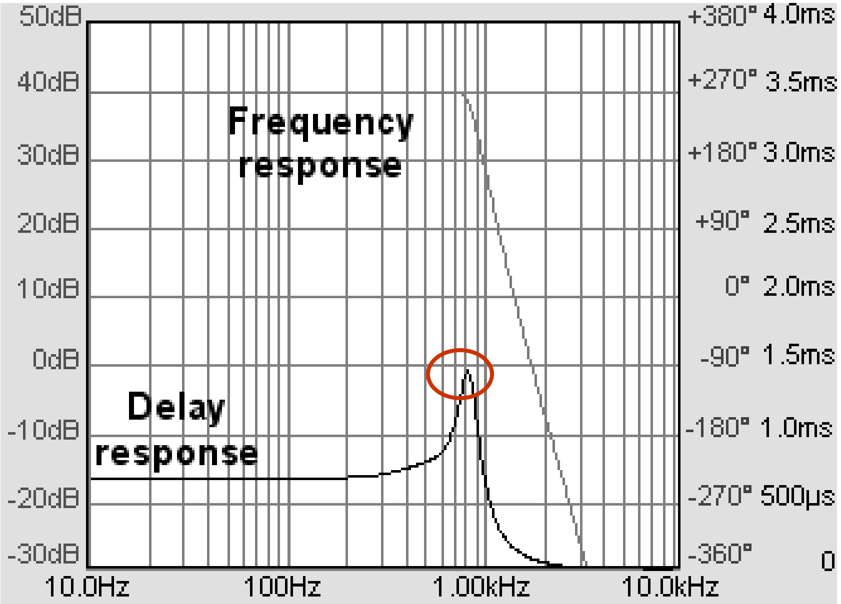
High Q Problems



- High Q filters "ring" at the cut off frequency
- *Very much like striking a bell*
  – Sharp blow to a bell causes it to ring
- High Q filters are *"struck" by band noise* - *Ringing!*

- Ringing typical of simple *cw crystal filters*
  – Bandpass response rings at both *high* & *low* edge
  – Can be very fatiguing to listen to when the band is noisy
- Ears "don't like" sharp delay/phase variations

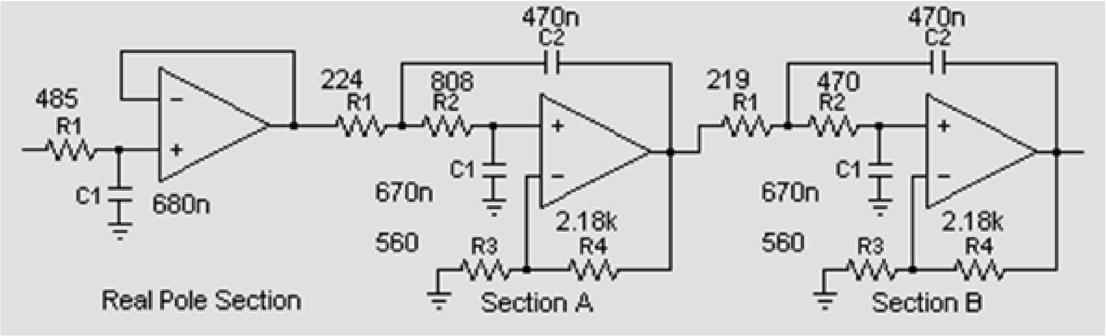
Limit Use of Q



- Limiting Q to ~ 3 or less in R/C active filter sections minimizes the tendency to ring
- Delay variations at filter edge are broader
- Filter looses some roll off steepness
  - *48* db vs. *60* dB down at 2 KHz

=> However, filter sounds much better!

Resistor Value Considerations



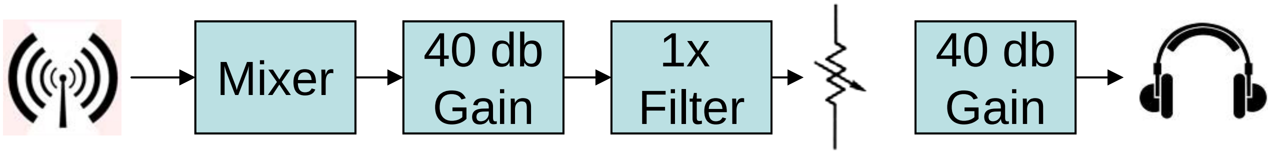
- *Resistors produce noise!*
  - *50* ohm resistor produces ~ *0.85* nV/SqrtHz
- *4x* the resistance produces *2x* the noise voltage
  - *200* ohms produces ~*1.75* nV/SqrtHz
  - *1M* ohm => Squareroot(1000000/50)*0.85 = *120* nV/SqrtHz (*very high*!)
- 10x voltage gain raises the noise floor, reduces the impact of resistor noise
  - *50* ohms of noise before *10x gain* the same as a (10)*(10)*50 or *5K* resistor after gain
- Best audio op-amps produce *0.85* nV/SqrtHz, but are expensive (LT1115, $4)
- Cheap low noise op-amp (LM5532, LM833, $0.30) produce ~*4.5* nV/Sqrt Hz
  - Same noise as a (4.5/0.85)*(4.5/0.85)* 50 = *1400* ohm resistor

=> Use low value resistors (~200 to 500 ohms) in very low level audio work (like receiver front ends) before first filter gain stage

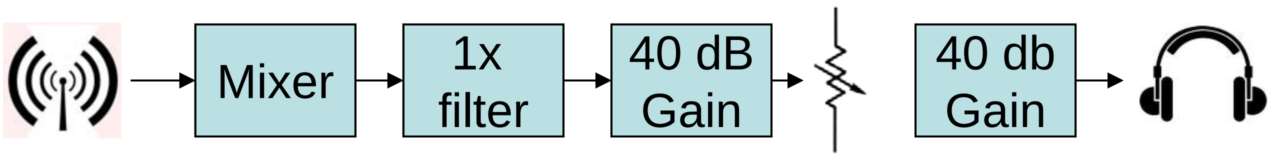
Filter Gain Considerations

- Almost all active R/C filters I have seen have *no* gain
- Receiver needs ~ *80 to 90 dB* of gain to drive headphones
- Volume control seems to work best placed at *mid point* in gain chain
  - Volume at the antenna or at the audio output causes problems
  - Halfway allows almost dead quite audio when the volume is turned all the way down
- Want ~ 40 dB of gain before volume control, 40 db after
- If 40 dB gain *before* 1x gain filter, 40 dB gain section *overloads easily*
  - 40 dB section has no off frequency protection to strong signals
- If 1x gain filter is *first*, then 40 dB gain, *receiver is deaf*
  - Noise of op-amps and resistors in the 1x filter kills the sensitivity

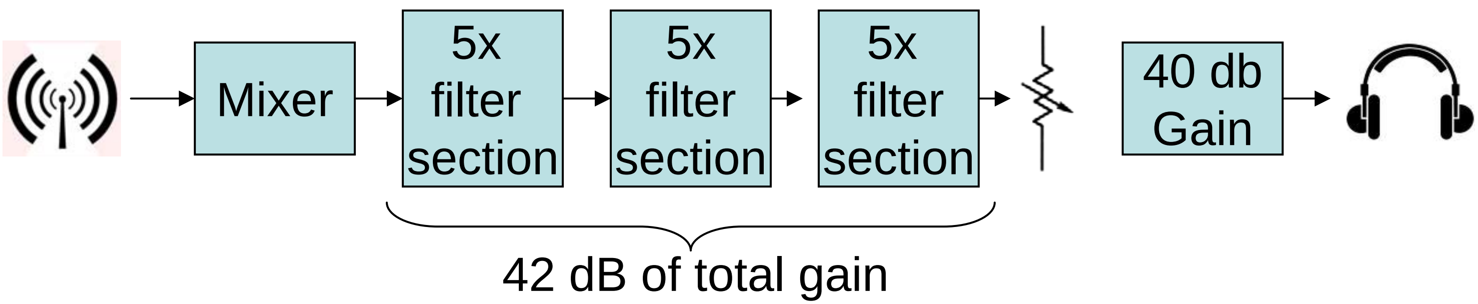
Distributed Filter Gain – Powerful tool



- 40 dB gain block before filter subjected to *signal overload*



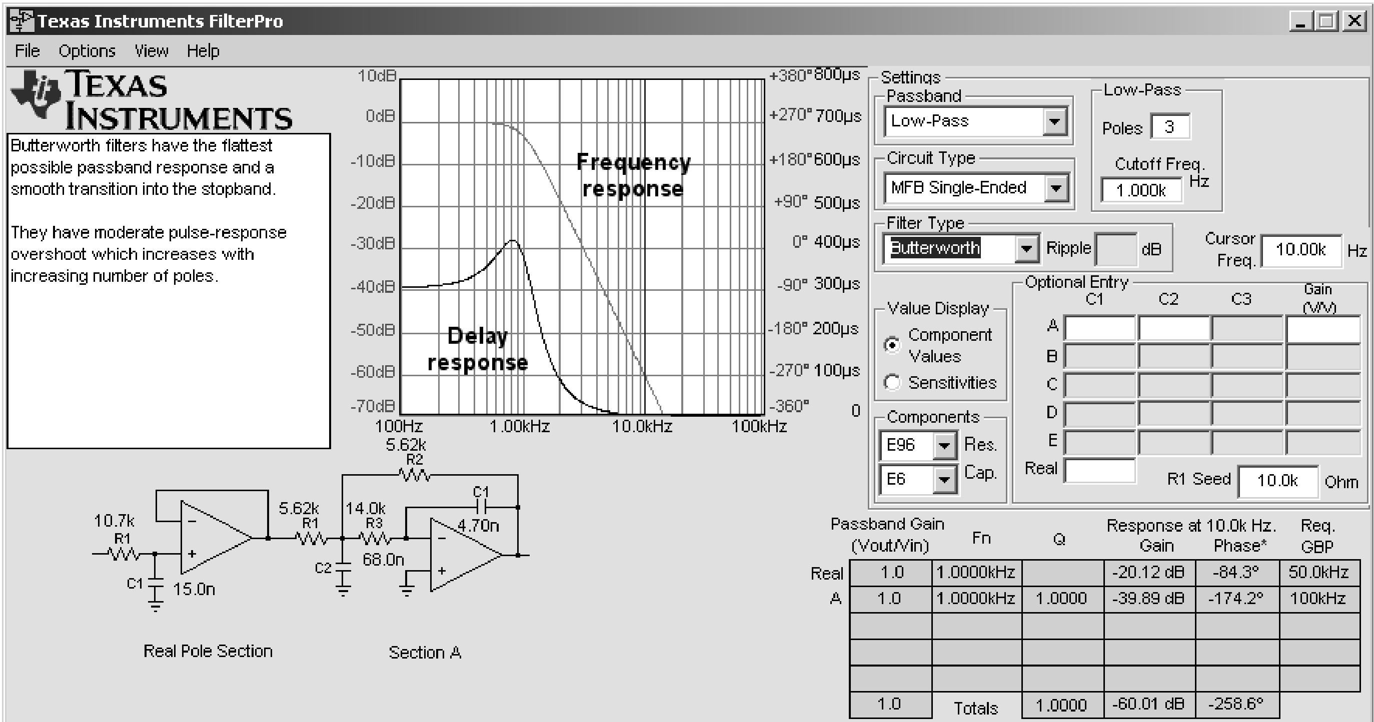
- Too much filter noise at very weak signals – *deaf RX*!



- Best design: *Give each section of the filter a little bit of gain*
  - Normal filter has *multiple sections*

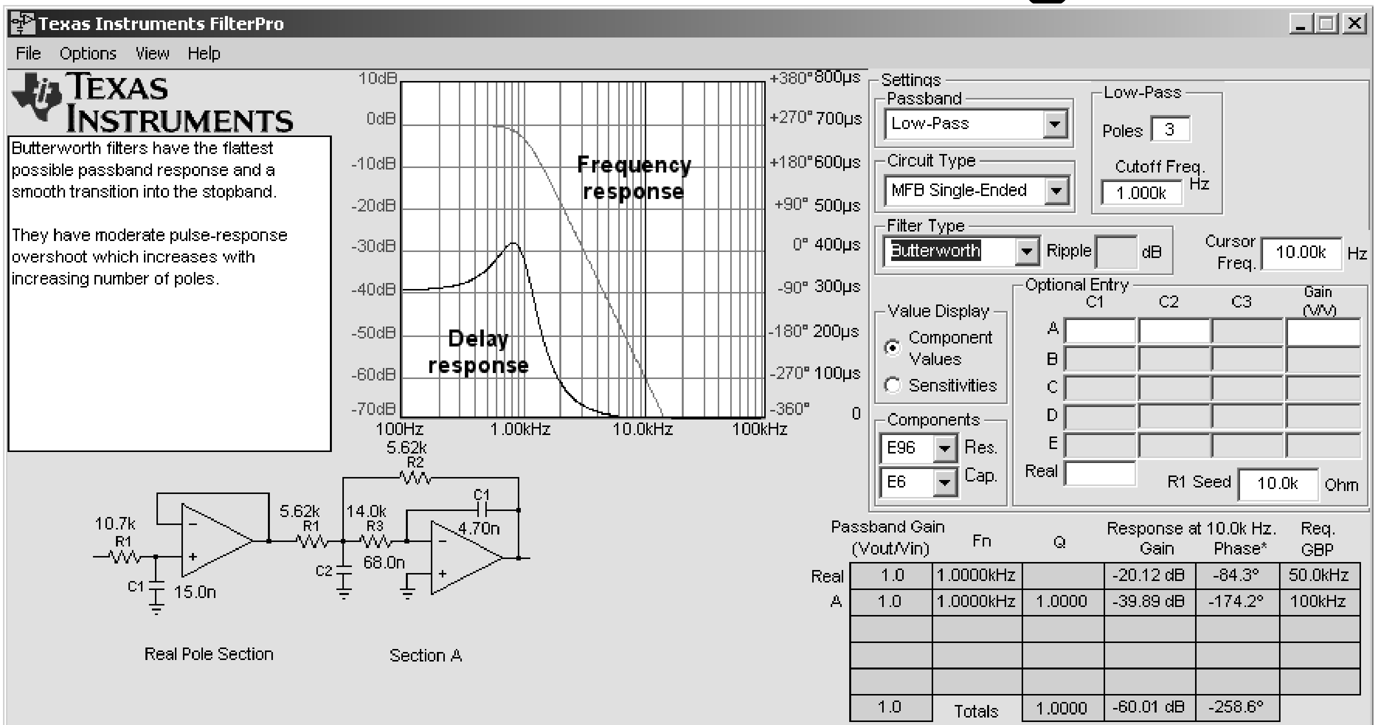
=> Filter protected gain - Significantly higher RX performance

Active R/C Filter Design Tool



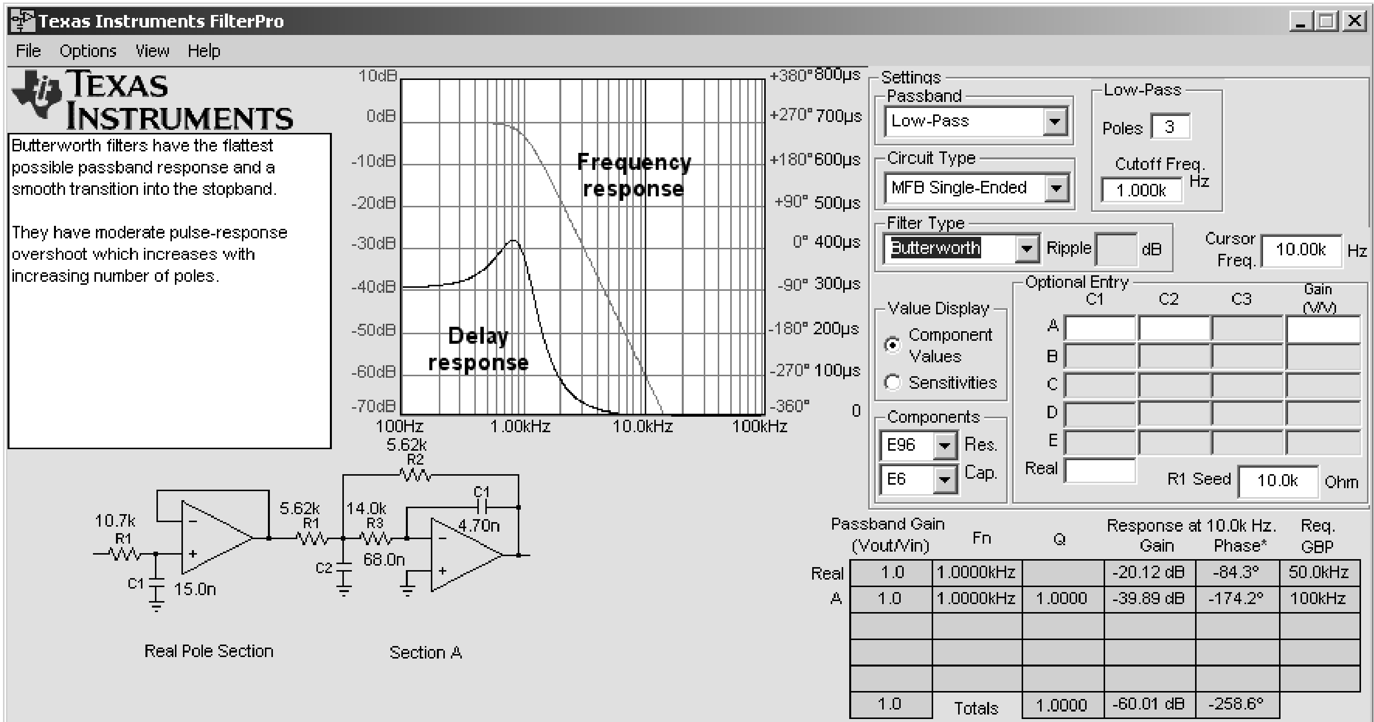
- TI FilterPro – Freeware available at http://focus.ti.com/docs/toolsw/folders/print/filterpro.html
  - or go to www.ti.com and search for “FilterPro”
- Designs Highpass, Lowpass or Band pass filters
  - Bandpass filters are simple low pass and high pass filters in series

Active R/C Filter Design Tool



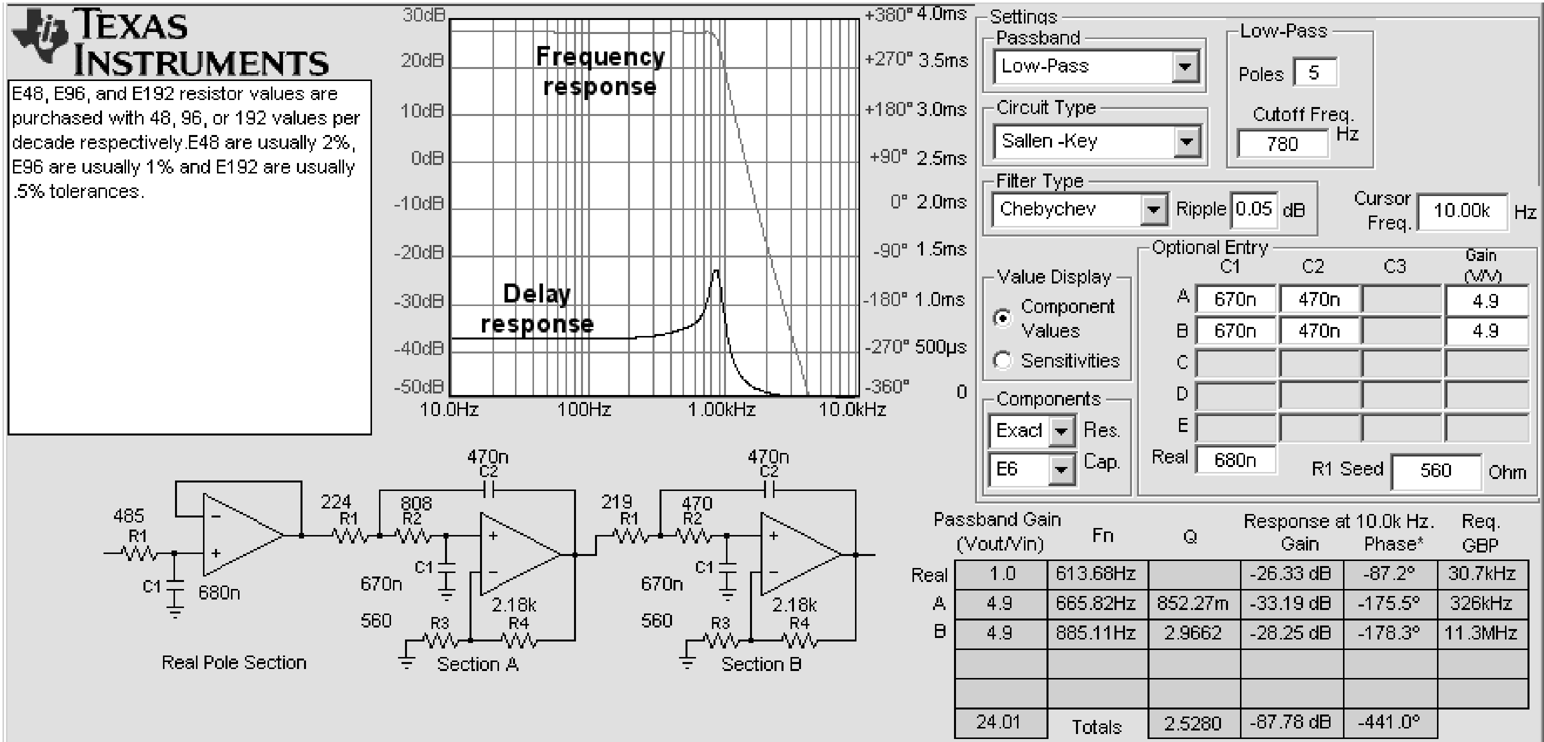
- Pick Chebychev filter
  - Changing Chebychev “ripple” changes the Q of the sections
  - *Allows designer to pick the maximum Q*
- Set the Circuit type from MFB to Sallen-Key
  - Gives better “C” values when used with gain
  - Set the R1 “seed” to 500 to 1K ohm (less noise)

Active R/C Filter Design Tool, cont



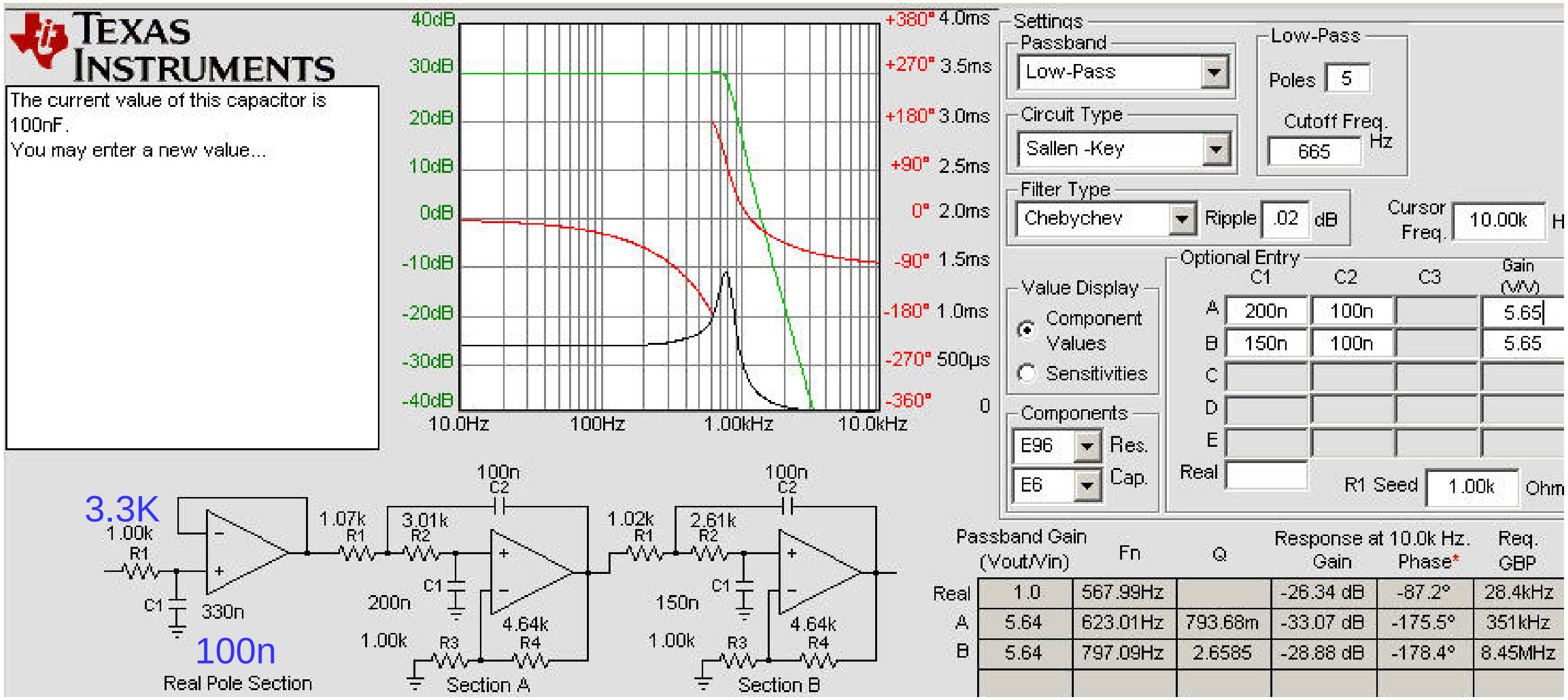
- Set cutoff frequency (800 Hz?)
- Adjust number of poles (3 used here) to get desired freq roll off speed
- Play with C1, C2 for each stage for best known resistor match
- Tweak “cutoff freq” and “ripple” to slightly adjust R values when close
- Goal: Get to as few unique parts as possible using common values

Sample CW Filters



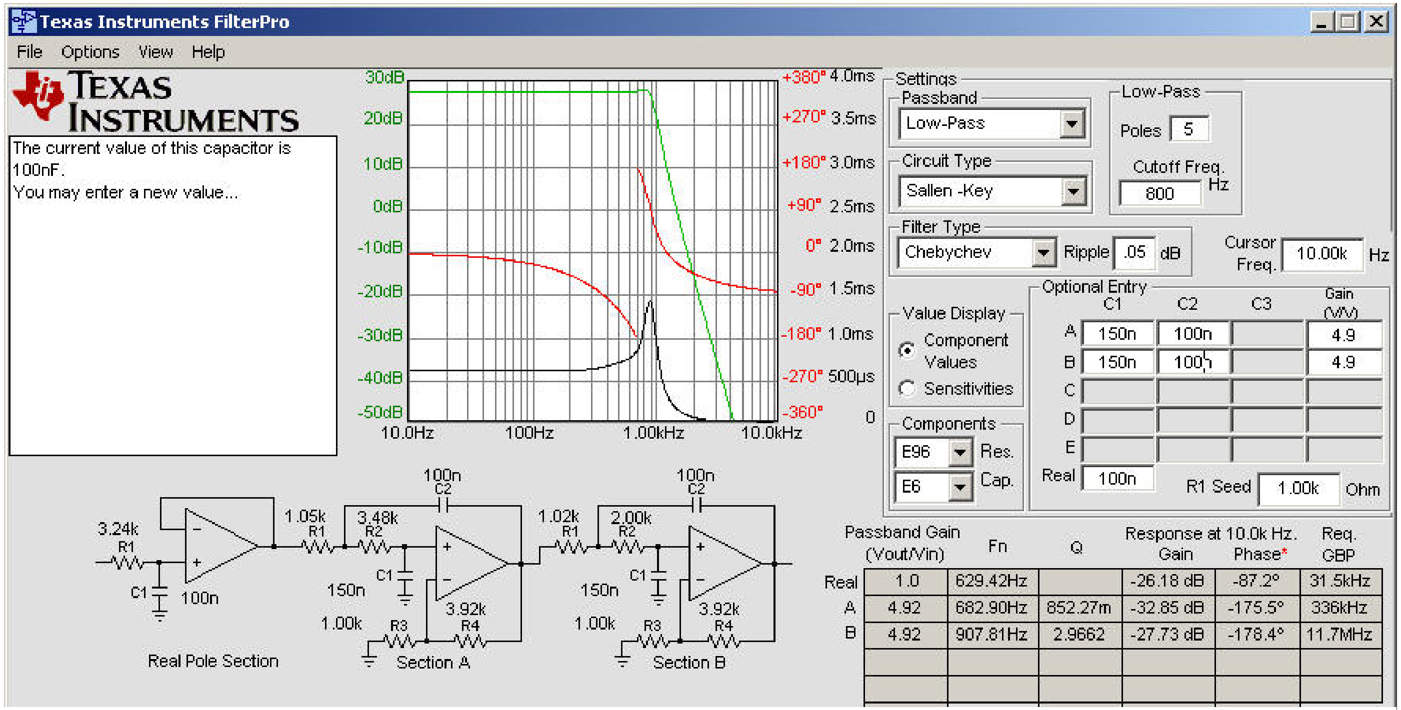
- Design # 1: 780 Hz, 48 dB down at 2 KHz
- Rs: 220, 470, 560, 2.2K (808 = 560 + 220)
- Cs: 0.47 uf, 0.1 uf (0.67 uf = 0.47uf + 2x 0.1uf)

Sample CW Filters



- Design # 2: 660 Hz, 50 dB down at 2 KHz
- Rs: 1K, 2.7K, 3.3K, 4.7K
- Cs: 0.1 uf (0.2 uf = 2x 0.1) (0.15uf = 0.1 + 2x 0.1 in series)
- 5 unique Rs and Cs total (out of 14 possible)

Sample CW Filters

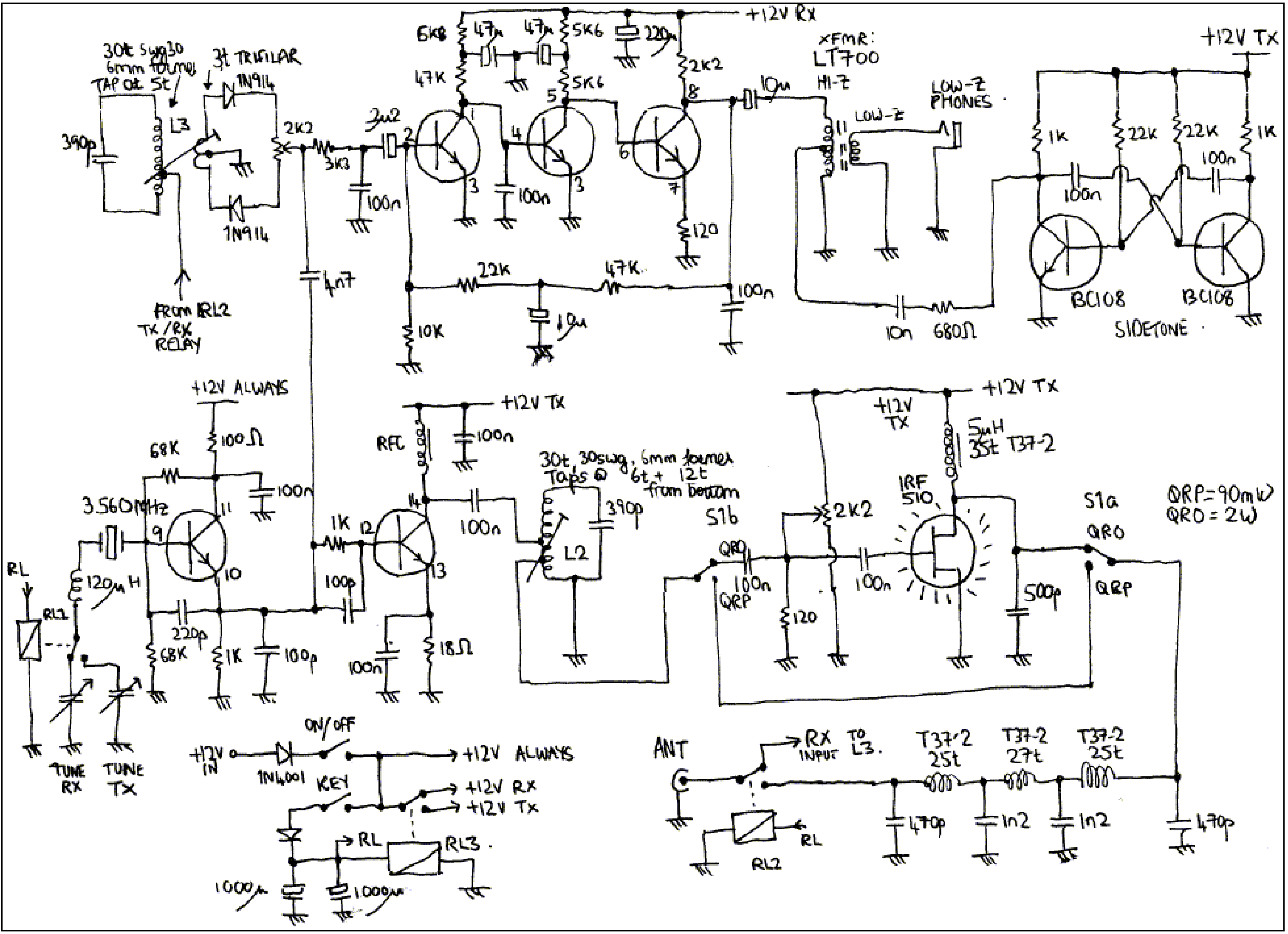


- Design # 3: 800 Hz, 46 dB down at 2 KHz
- Rs: 1K, 3.3K, 3.9K (2K = 2x 1K)
- Cs: 0.1 uf (0.15 uf = 0.1uf + 2x 0.1uf in series)
- Only 4 unique Rs and Cs total!

Main Take Away Points

- *Design tools* make R/C filter design easy
- Keep filter section Q *below ~3*
- *Beware of resistor noise!*
  - Use *low values* resistor for the first filter stage
  - 1M ohm resistors do not belong in very low level audio sections
- *Distributed gain* in each filter section produces high performance *filter protected* gain blocks
- Playing with the results can produce filters with both *few unique parts* and *common part values*

Original Unichip 80 DC Xcvr

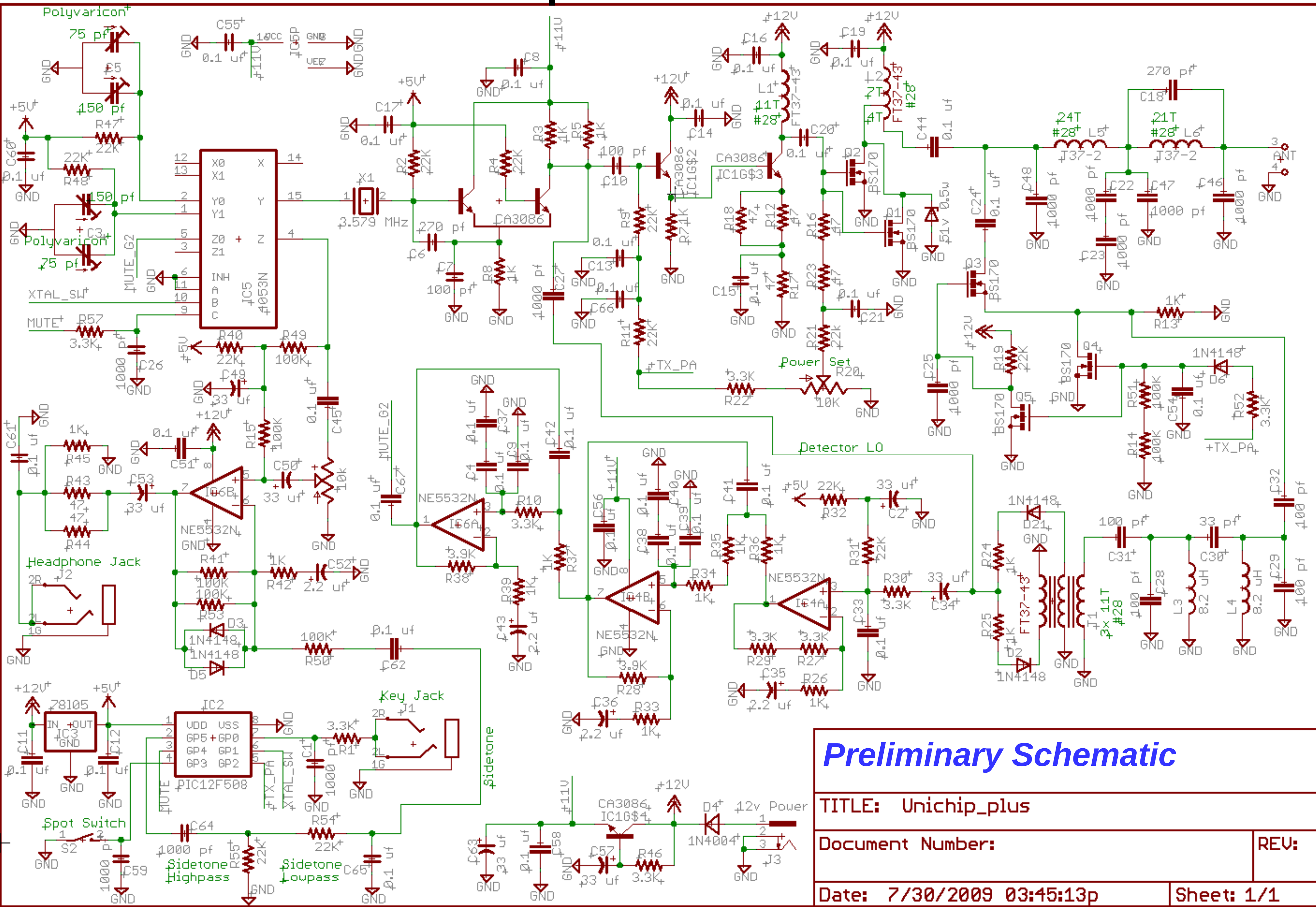


Aug 1, 2009

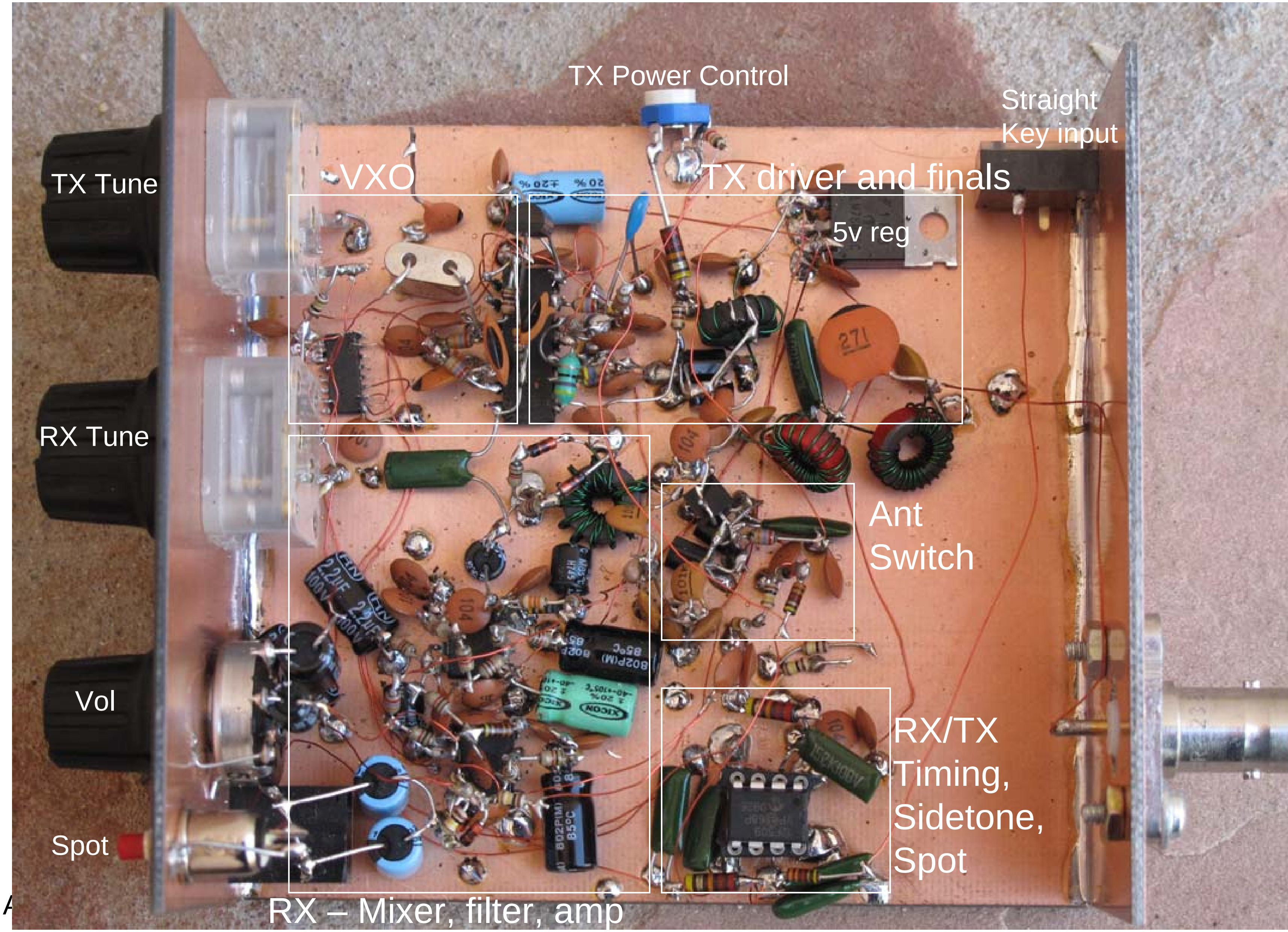
Observations

- 3 relays ($1 to to $2 each)
- $2 Audio xfmr
- Slug tuned cores in RF tuned circuits
- No mute
- No volume control
- No TX Spot
- No key click filtering
- No RX-TX chirp protection
- No ear protection (audio limiter)

New Unichip Plus 80 DC Xcvr



Unichip Plus Deadbug Prototype



Unichip Plus 80m DC XCVR

- Three main goals in Unichip Plus Design
  - *Low total cost*
  - Low number of *unique parts*
  - Good RX audio filtering (*sharp + low noise + low distortion + no ring*)
- Parts counts (excludes PCB, wire, and off board parts)
  - 2N2XX: 88 unique parts
  - BITX20: 57 unique parts
  - Unichip: 43 unique parts
  - DC40B: 38 unique parts
  - Unichip Plus: *28* unique parts, half are R's and Cs.
- Unichip Plus uses only *6* R values, *7* C values
  - 47, 1K, 3.3K, 3.9K, 22K, 100K
  - 33 pf, 100 pf, 270 pf, 1000 pf, 0.1 uf, 2.2 uf, 33 uf
  - Some were combined (series/parallel) to make other values

=> Fewer unique parts minimizes the kitting effort

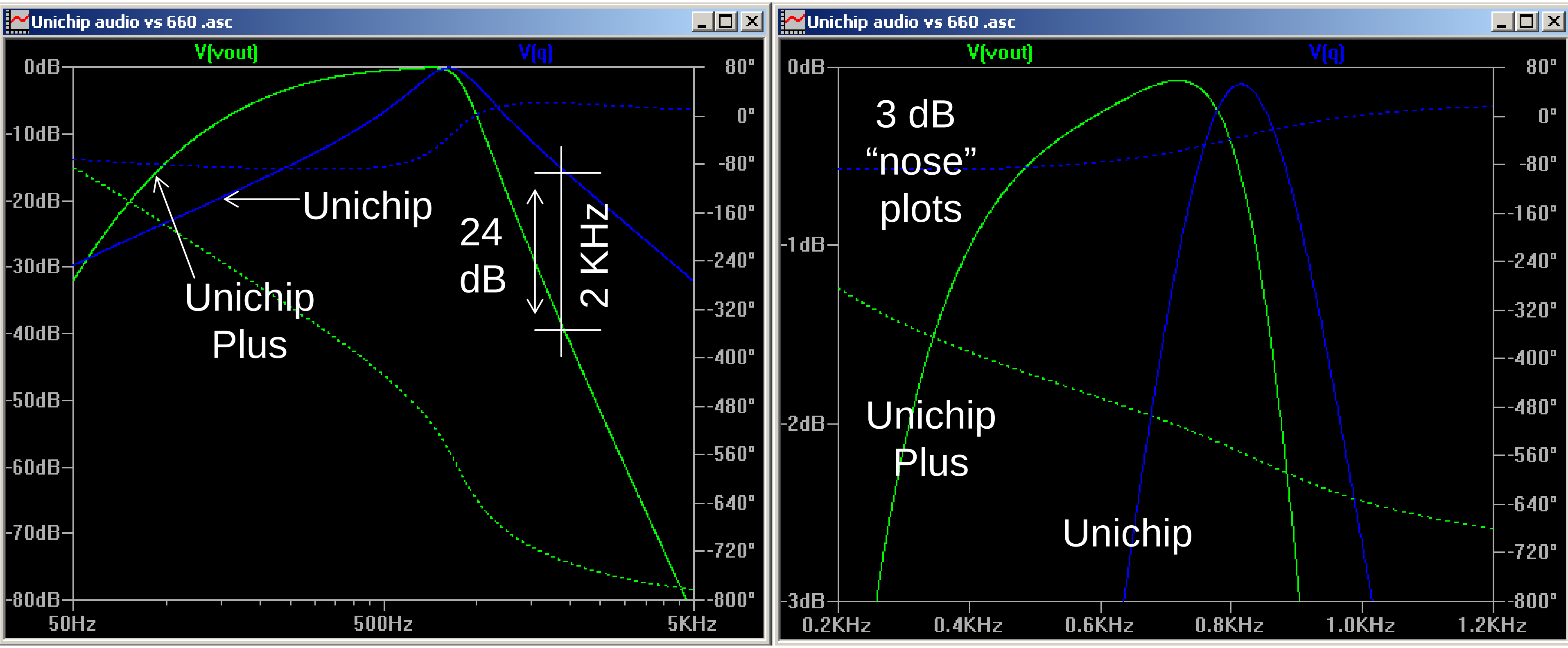
Unichip Plus Initial Specs

- Nominal Frequency: 3.5791 – 3.580 KHz
- VXO tuning range *~ 0.9 KHz (not much!)*
- Current drain
  - RX: No signal *20* mA, moderate signal *23* mA
  - TX: 2-3w max. Output adjustable, *0.25w min*, *680 mA @ 3.2w*
- Receiver Sensitivity: *-113 dBm* (0.5 uV rms)
- Measured receiver filter response
  - 10 dB down at 1.4 KHz, *30 dB* at 2 KHz
  - *50 dB* down at 3 KHz, *70 dB* at 4.8 KHz
  - *100 dB* down at 9.4 KHz

Unichip Plus Improvements

- Mute circuit
- Volume control
- Sharper cw audio filter
- Diode protected audio output
- Spot switch
- Controlled RX-TX transition (no chirps, no key clicks)
- Low noise, low distortion audio chain
- “No Tune” RF filtering
- Improved DC power filtering
  - Eliminates DC receiver “howl”
- Improved VXO buffering
- No relays – solid state antenna switch

Unichip vs. Unichip Plus Freq Response



- Unichip Plus has wider 600 Hz audio pass band with much steeper high side filter cut off
  - *40* dB vs. *16* dB down at 2 KHz
  - *80* dB vs. *30* dB down at 5 KHz