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

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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

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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

- 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

Note the very sharp delay spike at the cutoff frequency
Characteristic of high Q filters
Q = 5 here
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 loses some roll off steepness
  - 48 dB vs. 60 dB down at 2 KHz

=> However, filter sounds much 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 => Square root(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

  - 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

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)

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Unichip Plus Deadbug Prototype

RX – Mixer, filter, amp

VXO

TX driver and finals

TX Power Control

5v reg

Ant Switch

5v reg

RX/TX Timing, Sidetone, Spot

Straight Key input

Vol

Spot

RX Tune

TX Tune
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