Building A Better C-QuAM® Decoder

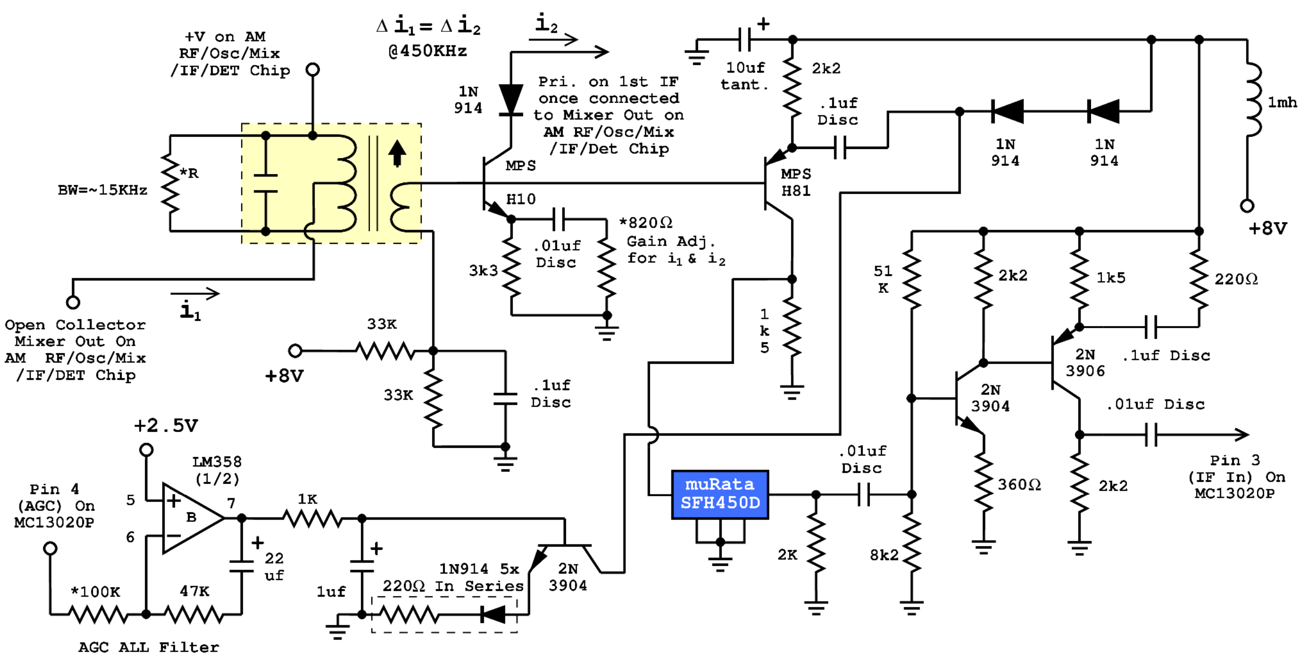
In building a C-QuAM® decoder to use as a converter for existing tuners there are several criteria that need to be met in order to make one that will offer good performance and consistent frequency response across many different tuners. Tuners have varying bandwidth and for good performance need a defined bandwidth for the IF so post detection filtering can flatten out the response in regard to NRSC de-emphasis. Most mixer outputs are an open collector fed into a tuned IF transformer so this is the prime spot to tap into and reroute the IF signal into the decoder. By disconnecting the mixer from the primary of the first IF transformer and sending it to the decoder supplies the decoder with a bandwidth limited only by the tuned RF antenna. In order to make the RF AGC still function the IF signal needs to be returned to the first IF transformer. This is done by the MPSH10 transistor that is connected to the secondary of the IF transformer on the decoder board. This transistor has an selectable emitter resistor (820Ω) to adjust the signal level collector output relative to the signal level input of the decoders IF transformer. By having the modulating current output equal to the modulating current input of the decoders IF transformer insures that the original AGC loop circuit functions the same prior to adding the decoder. This gain adjustment can also be used to compensate for poorly designed AGCs that need a bit more or less gain for better AGC performance in the original circuit.

For the signal for the decoder itself the MPSH81 transistor is also connected to secondary of the decoder's IF transformer. Both transistors have swamped emitters and present minimal load on the IF transformer so its Q is not diminished much compared to its unloaded state when the decoder's AGC is not maxed out. The optimal loaded Q for the decoders IF transformer is 30 which offers a bandwidth of 15KHz at 450KHz. If the Q is too high a loading resistor can be added on the primary of the transformer to increase the bandwidth to 15KHhz. The collector output of the MPSH81transistor uses a 1.5KΩ to ground to set the correct output impedance to drive the ceramic filter. The emitter of the MPSH81 has a variable resistance load for AGC control created using two diodes in series. The AGC works by varying the current through two diodes. This current is converted from a voltage developed by a PLL style loop filter using an Op-Amp creating an ALL (Amplitude Locked Loop) AGC. The input to the ALL filter is obtained from a pin on the decoder for signal level. This method insures that the unmodulated input level to the ceramic filter and the decoder is kept exactly the same throughout the range of the varying gain of the AGC amp. While the original tuner's AGC loop is still functional since the IF signal has been returned to it most AGC circuits do not hold a consistent level throughout their range but as long as the output into the decoder falls within the control range of its AGC a constant level audio output will be maintained in relation to modulation level, a feature normally associated with FM receivers.

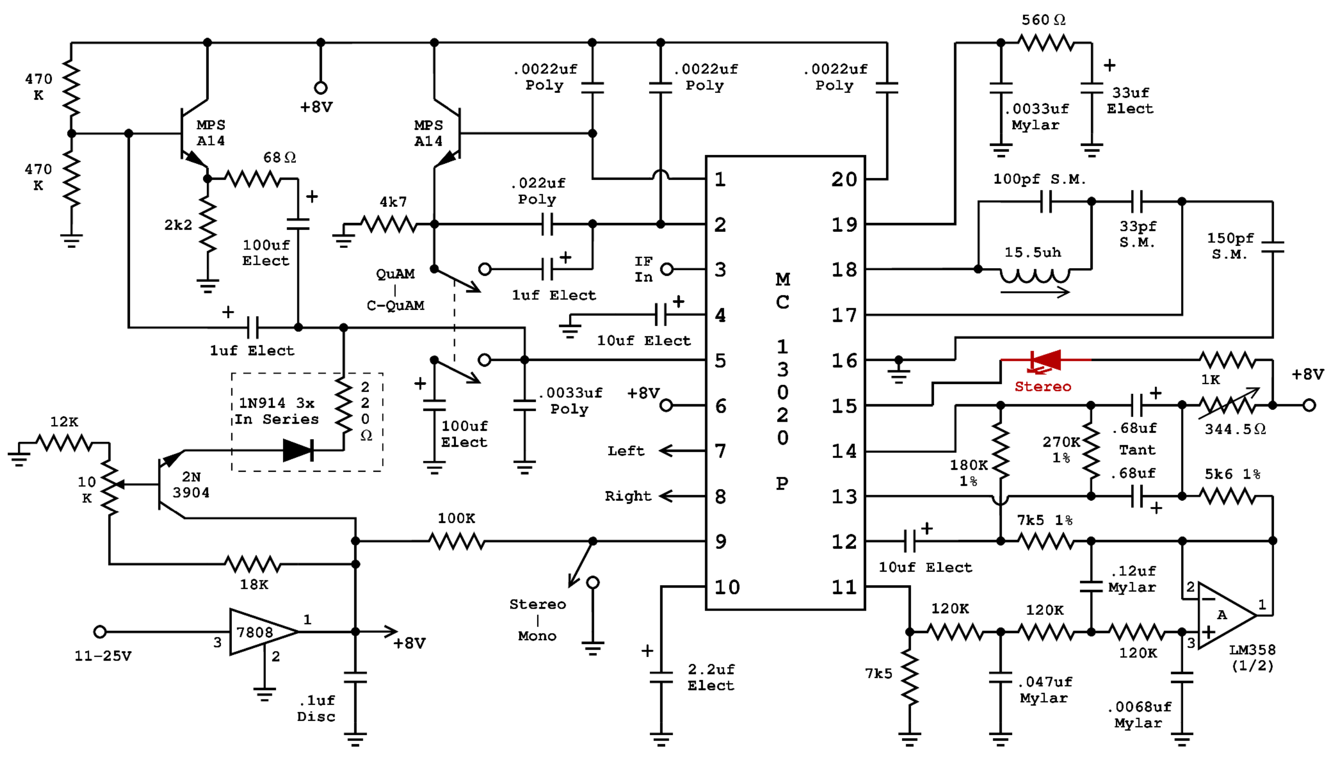
A Gaussian style ceramic filter is used that has a flat Group Delay Time (GDT) in the passband so the C-QuAM® predistorted sidebands arrive at the same time relative to the fundamental modulating frequencies allowing the cosine correction circuit in the decoder to more accurately remove the C-QuAMing® distortion there for envelope compatibility of monophonic receivers.

Normally a ±7.5KHz filter would be ideal but with the varying range of RF bandwidths of the many receivers out there, the post detection filtering providing a ~10dB boost at ~9.5KHz for a flat audio response and the steep skirts of the ceramic filter in the 7.5-10KHz range produces some audio ringing that is very noticeable on program material containing a heavy and/or compressed top end. The ±7.5KHz ceramic filter along with the RF bandwidth of the antenna provides good adjacent carrier suppression of >15dB which makes a good all around choice for a single IF filter instead of a dual wide/narrow filter scheme requiring an additional switch installed on the receiver. Using a ±10HKz ceramic filter allows for a flatter usable passband response with less ringing and more leeway for a flat passband adjustment using the loading resistor on the IF transformer on the decoder board. LC based IF filters tend to have little if any ringing compared to ceramic filters in the roll off range so this will offer an improvement in sound quality.

While the attenuation of adjacent carriers is less it is partially compensated by using a blend to QuAM circuit on the decoder so the QuAM to C-QuAM® ratio is 6:1 at 10KHz and the top end is synchronously detected mostly as QuAM. This also helps reduce top end envelope detector distortion caused by sideband reception asymmetry, an issue when the RF & IF filtering is not tuned to the exact center of the signal. When using the ±7.5KHz ceramic filter the IF input transformer on the decoder would need a Q of ~10 for minimal bandwidth reduction offering minimal rejection of mixer harmonics thus potentially overdriving the diodes linear range used for AGC control and distorting the signal. Having the Q of this IF transformer at 30 when using the ±10HKz ceramic filter helps reduce the harmonics to a minimum.



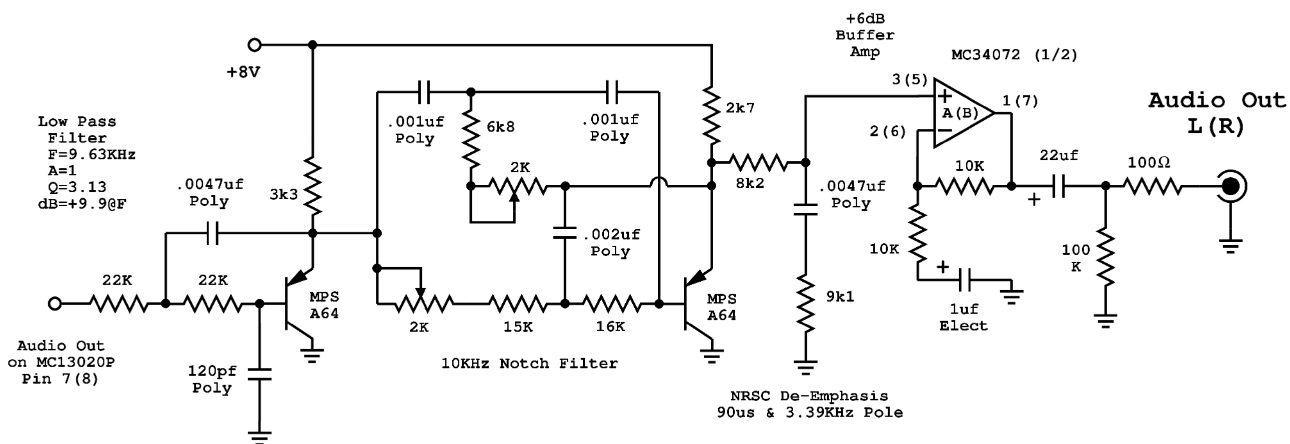
Most of my experience with C-QuAM® decoders has been with the Motorola® MC13020P chip and I did not test the MC13028 chip until years later. This chip being their first one has some major flaws with both cosine correction and pilot detection that where later addressed in the newer chips. One would ask why build a decoder using the MC13020P decoder with all its flaws over the newer ones. Well only having the MC13020P chip to work with provided motivation to work around these issues. The fatally flawed cosine correction circuit posed major problems for clean reception of stereo signals under less than marginal conditions. It comes from the fact that the output of an envelope detector is always positive while the synchronously detected I signal also has negative modulation. When both the Env and I Det signals are sent to the Err Amp to develop the 1/Cosθ distortion correction term the negative feedback of the cosine correction circuit turns into positive feedback when the I Det goes negative. This positive feedback causes the circuit to latch up and the gain amp goes to maximum and flattops. This is modulated into the synchronously detected L-R (Q Det) signal creating distortion much greater than ever experienced with envelope detection during interference conditions. This situation also occurs when the phase approaches ±90° caused by interference and the gain amp goes to maximum. Having the Env Det, Err Amp & I Det pins on the MC13020P allows the addition of external components to tame cosine correction and blend to synchronously detected QuAM for the top end or switch to full synchronously detected QuAM during high interference levels. Having synchronous detection available allows reception of distant weak and noisy signals that are normally unintelligible with an envelope detector. The newer chips especially the MC13028 have none of these pins available so they have to be used as is and only offer envelope detection for L+R. When the MC13020P is used in QuAM mode it offers better stereo reception during higher interference levels than the newer chips.



Cosine correction bandwidth has been reduced by a factor of 3.3 over the typical bandwidth used for a ±5KHz IF filter by increasing the capacitance value at Pin 5, the Err Amp, to .0033μ*f*. This is of little consequence since maximum cosine modulation is mostly produced by bass and lower midrange frequencies while the upper frequencies are less and produce less. Also sideband asymmetry for the higher frequencies produce more envelope detection distortion which is then modulated into L-R and limiting cosine bandwidth may at worse replace the odd ordered harmonics with the more pleasant even ordered ones. A high pass filter at ~55Hz has also been added to the Err Amp to help reduce but not eliminate distortion caused by co-channel interference. This is done by simulating an inductor with a buffer amp, resistors and capacitors. The blend to QuAM or full QuAM mode is accomplished by driving the Env Det Pin which has an impedance of 4.3KΩ with a buffered low impedance I Det signal. A darlington source follower is used as the buffer amp and is coupled to the Env Det Pin via a .022μ*f* capacitor for a blend to QuAM crossover frequency at ~1.6KHz and for full QuAM mode a 1μ*f* capacitor is also added via a switch. The bandwidth of the Cosine Err Amp is also reduced by the same factor with its .0033μ*f* capacitor and is completely disabled with a 100μ*f* capacitor for full QuAM mode using the same switch. To pick a different crossover point for the err amp use the .001μ*f* capacitor value normally used with a ±5KHz IF filter and scale it in reference to the new crossover point in relation to 5KHz. For blend to QuAM use this same frequency to replace the .022μ*f* capacitor with a new one for a corner frequency in association with the 4.3KΩ impedance at Pin 2.

The other issue is the pilot filter and its components not being selected properly to provide adequate pilot level for the detector circuit. The ACD'd Q signal is also used for co-channel detection and needs to have good low pass filtering above 40Hz. The output of Pin 11 is filtered with a third order VCVS low pass filter at 40Hz providing an 18dB/Oct. roll off. The bandpass filter for the pilot has been increased to a Q of ~14 over the recommended value of 10. With this narrower bandwidth precise tuning is needed so a TrimPot is used for fine tuning. The .68μ*f* capacitors used in the pilot filter must be temperature stable and high Q low ESR. Good choices are polystyrene or tantalums. With the selected resistors the pilot bandpass filter has a gain of 24 with the maximum being 25. With the selected resistors for co-channel and pilot filters a complete nulling of the pilot is available at the co-channel input when the pilot bandpass filter is tuned to a center of 25Hz when there is a pilot tone present from a stereo signal. Having the 10μ*f* capacitor associated with Pin 12, the co-channel input, removed from the circuit will aid in tuning of the pilot filter while checking for nulling since the input impedance is 2KΩ making it more of a current source/sink. All these tweaks for the AGC'd Q signal provide superior co-channel sensing and pilot detection.

The last processing done is post detection to provide passband equalization, 10KHz whistle filter, and NRSC de-emphasis. Equalization and low pass filtering is provided by an second order VCVS low pass filter. This filter has a Q of 3.13 providing a 9.9dB boost at its corner frequency of 9.63KHz. While the ceramic filter is a wide ±10KHz with a flat passband the LC RF & IF filters have a gradual roll off for the higher frequencies and an additional low pass filter necessary to meet the NRSC response in the midrange further attenuates the higher frequencies. The VCVS filter flattens out the overall response out to 9.5KHz. To remove the 10KHz whistle from adjacent channel interference a bootstrapped Twin-T Notch filter is used to provide a maximum Q of 50. Having the Q this high requires that the filter be precisely tuned and temperature stable capacitors used to eliminate drift. Two TrimPots on each filter are needed to provide a good >60dB attenuation and a highly accurate 10KHz oscillator is needed to calibrate them. The NRSC filtering specifies a 75µs de-emphasis with an 8.7KHz pole providing a 10dB reduction at 10KHz. Since RF & IF filtering response creates a curved response attenuating the higher frequencies a NRSC pre-emphasized signal entering a receiver has a ~3dB boost at 4.5KHz and a ~6dB attenuation at 10KHz, a de-emphasis curve with less attenuation is necessary. Adding in the RF & IF response and the VCVS low pass filter with a Q of 3.13 requires a de-emphasis of 90µs with a 3.39KHz pole to make a flat response. The output of the NRSC de-emphasis filter needs to be buffered and the output level of the MC13020P chip is a bit weak compared to other line level signals so a +6dB buffer amp is provided to bring it up to line level.



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