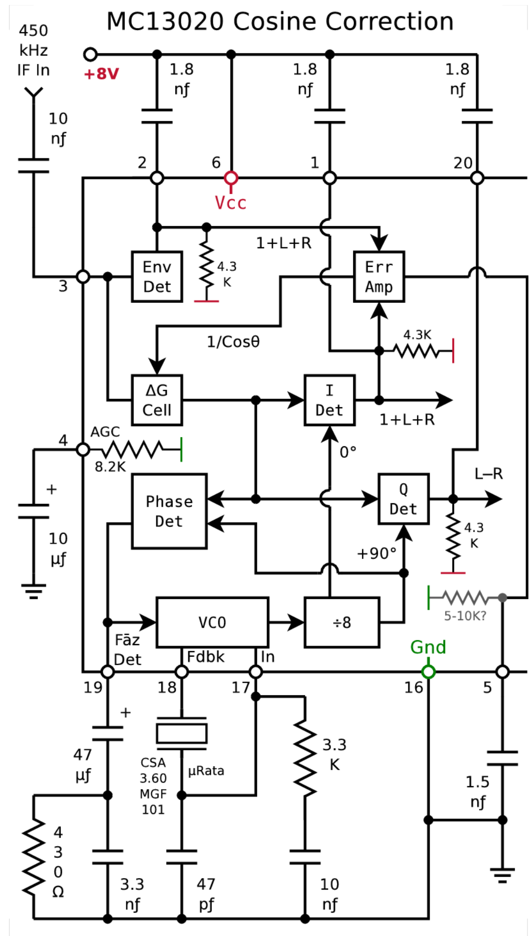
Issues With C–QUAM Decoding Under Less Than Optimal Conditions

C–QUAM reception performance is on par with QAM during strong signal low noise/distortion situations but unlike QAM, which shows major strength without distortion under marginal conditions, C–QUAM starts falling apart as signal conditions worsens. When the S/N drops below 21dB the decoding process starts **Expanding the Noise !** This is a direct consequence of forcing the envelope to carry **L**+**R** for mono compatibility and the 1/Cosθ correction factor applied to **L**–**R** during decoding. One of the main factors of this degradation is the co-channel beat note interference inducing PLL and cosine correction mis-tracking. QAM is also prone to its effects and can cause **L**+**R** to bounce between Left and Right speakers but this is more of a spatial rotation within the room. This beat note in the **Q** channel causes the cosine corrector to mis-track and this process greatly modifies this interference which alternately modulates the volume level between **L** & **R**. Along with what also happens with the regular QAM signal for C–QUAM it is a double whammy. Switching to QAM decoding for C–QUAM when co-channel induced platform motion occurs can greatly improve signal reception.

The best solution to minimize the effects of decoder mis-tracking, be it QAM or C–QUAM, is ISB. ISB has the unique characteristic of not mixing or modulating the signal levels between Left and Right channels during decoder mis-tracking but it does cause a modulated phase shift to to be applied to the detected signals which plays out in the environment. Under minor mis-tracking this is can go relatively unnoticed to acceptable where C–QUAM it is present and can be objectionable.

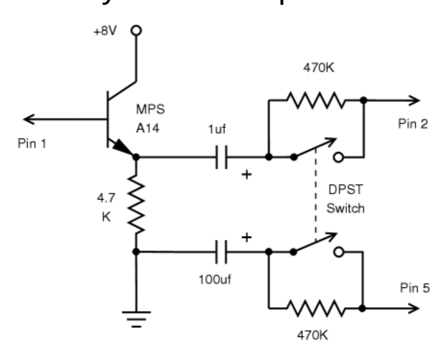
During the (+) peak modulations cosine correction error remains low as the angle of error is low and the ratio of desired to undesired signal is high resulting in minimal distortion during decoding. During the (–) trough modulations the ratio is greatly reduced and sometimes the instantaneous signal levels results in the undesired signal being the greater. In C-QUAM, unlike QAM, the envelope is forced to carry **1**+**L**+**R** and to keep the cosine correction decoding process within its limits single channel modulation is limited to 75% of **1**+**L**+**R** (envelope). The peak phase modulating limits at +75% is ~23⅕°, –75% is ~71⅗° and the 1/Cosθ (Secθ) gain factors are 1.088 and $\sqrt{10}$ respectively. It is during these negative modulating periods is when the cosine correction process is most vulnerable to noise and decoder mis-tracking. The peak phase deviation during this period is at its limits in order to maximize single channel modulation. When interfering noise is added in it can push the phase well past the tolerance point and as θ –> 90° Secθ° –> ∞ which causes radical amounts of gain well past the limits of the corrector circuit resulting in **L**–**R** clipping and thus producing distortion. In both QAM and C–QUAM the phase deviation is at its peak during negative modulation and while this has no effect on QAM detection C–QUAM becomes fragile during the decoding process.

ISB on the other hand, be it QAM or C–QUAM (C–ISB™) based, with the audio phasing produced by the PSNs and applied to the quadrature modulators has a unique effect on the incidental phase modulation. During the peak and trough modulating limits of the **I** channel the phase is at or approaching 0° and this has a positive effect on cosine correction as larger amounts of phase error produced by interfering noise has minimal effects on the amount of gain correction applied. At 0° an interference produced ±15° decoder tracking error only produces an ~3½% gain correction error but this amount of error under C–QUAM can approach ∞ as the phase approaches 90° with the ±15° decoder tracking error.

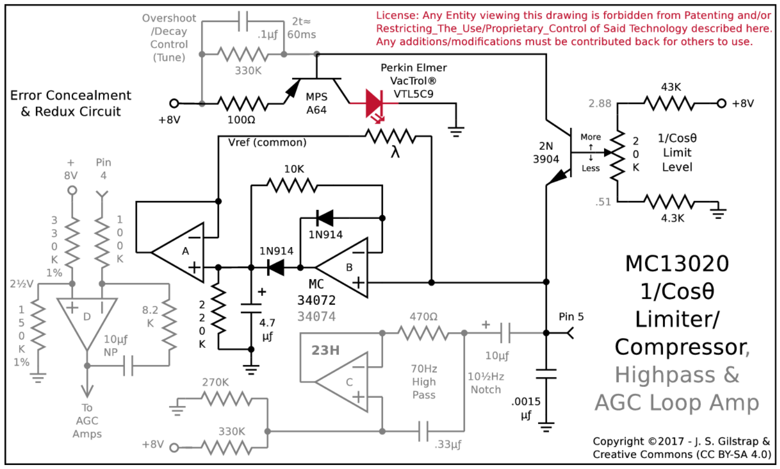


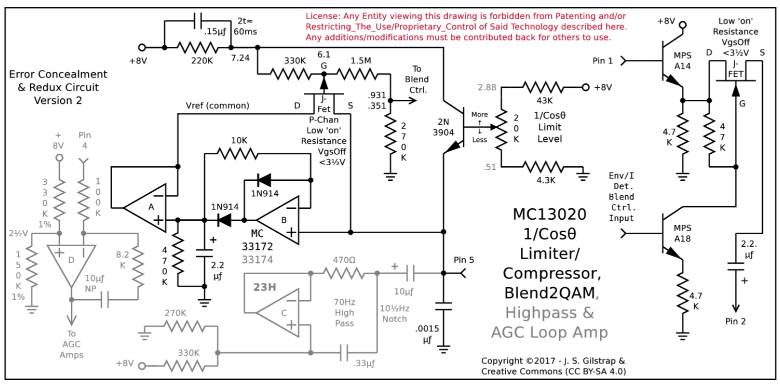
This is why Kahn ISB outperformed all the other systems under less than optimal conditions particularly sky wave. The channels are separated by frequency and not phase during transmission so asymmetrical sideband reception and decoder tracking error does not effect separation but will effect distortion cancellation, which is minor. Kahn's inverse modulator to minimize distortion in L–R detection only partially demodulated (limited) the envelope and signal phase does not enter into the equation so it is more likely to reduce the distortion effects produced by interference rather than expand it as C–QUAM does. While the Kahn system did have its detractors as in the decode process was not the inverse of encoding so perfect separation was not possible, it did produce very good results in real world use. Later versions did address the mathematical encode/decode symmetry issues though. His system had been refined enough though years of field testing and the good results of ~1% distortion and >20dB separation shows with signal quality degradation occurring more slowly under marginal conditions as compared to the other competing systems proposed.

The goal is to take this field experience and benefit from it to produce a decoding process that mimics the Kahn ISB system in areas where it excelled while also retaining the better qualities of C–QUAM to produce a system that rivals QAM, or ISB if audio PSNs are applied to C–QUAM. The Issue that plagues C–QUAM is the cosine corrector circuit and its performance on downward (–) modulation during periods of interfering noise which can produce large decoding errors. There are a couple of ways to address this. The simplest is to just switch to synchronous QAM decoding during marginal signal conditions, e.g. sky wave, and accept the minor loss of separation and and lack of distortion correction. This is a good and simple approach since the lack of distortion correction is barely noticeable under good conditions on regular program material and during marginal signal conditions the interference usually drowns out the effects of the pre-distorted L+R & L–R. QAM's synchronous detection for L+R also eliminates any harmonic mixing distortion produced by the envelope detector from interfering noise. For the 1st generation MC13020P C–QUAM decoder this is a simple addition that demonstrates the superiority of synchronous detection over envelope detection. In the drawing to the right is a circuit that when added to the MC13020P will switch from envelope based C–QUAM to full QAM synchronous detection. To prevent the ΔG Cell from modulating the signals going into the I Det & Q Det with 1/Cosθ the ΔG Cell is disabled at pin 5 with a 100µƒ capacitor. In order for the synchronously detected I signal to pass onto the de-matrix circuit inside the chip and appear in the L & R outputs the I signal, sourced at pin 1, is buffered with the MPSA14 Darlington transistor and AC coupled to pin 2, the Env Det. The impedance of pin 2 is 4.3K so driving it with a buffered low impedance source overrides the envelope signal not harming the chip. A DPST switch allows it to be switched out during tuning and when it is not needed.



There are more elegant approaches that only reduce distortion correction in varying amounts. Defeating distortion correction during peak (+) modulations has minimal effect on signal quality so whether or not this is applied is of little consequence compared to the gain/loss during the trough (–) modulations. Given this it is just as safe to disable cosine correction during moments of peak modulation when noise has caused adverse effects. At ~71⅗° deviation the gain of the ΔG Cell should never exceed $\sqrt{10}$ so when this is occurs the gain can be clamped down to 1 or reduced by varying amounts depending on the amount of distortion caused by the interference for short periods of time. The recommended 0 –> 90% attack time should be ~1ms and 100 –> 10% decay ~60ms. If varying levels of correction disabling is employed the process can be simple or sophisticated enough that interfering noise detection heuristics weighted with the psycho-acoustic perception of the human ear would produce an optimal balanced result that maximizes distortion correction while eliminating any perceivable effects from noise.

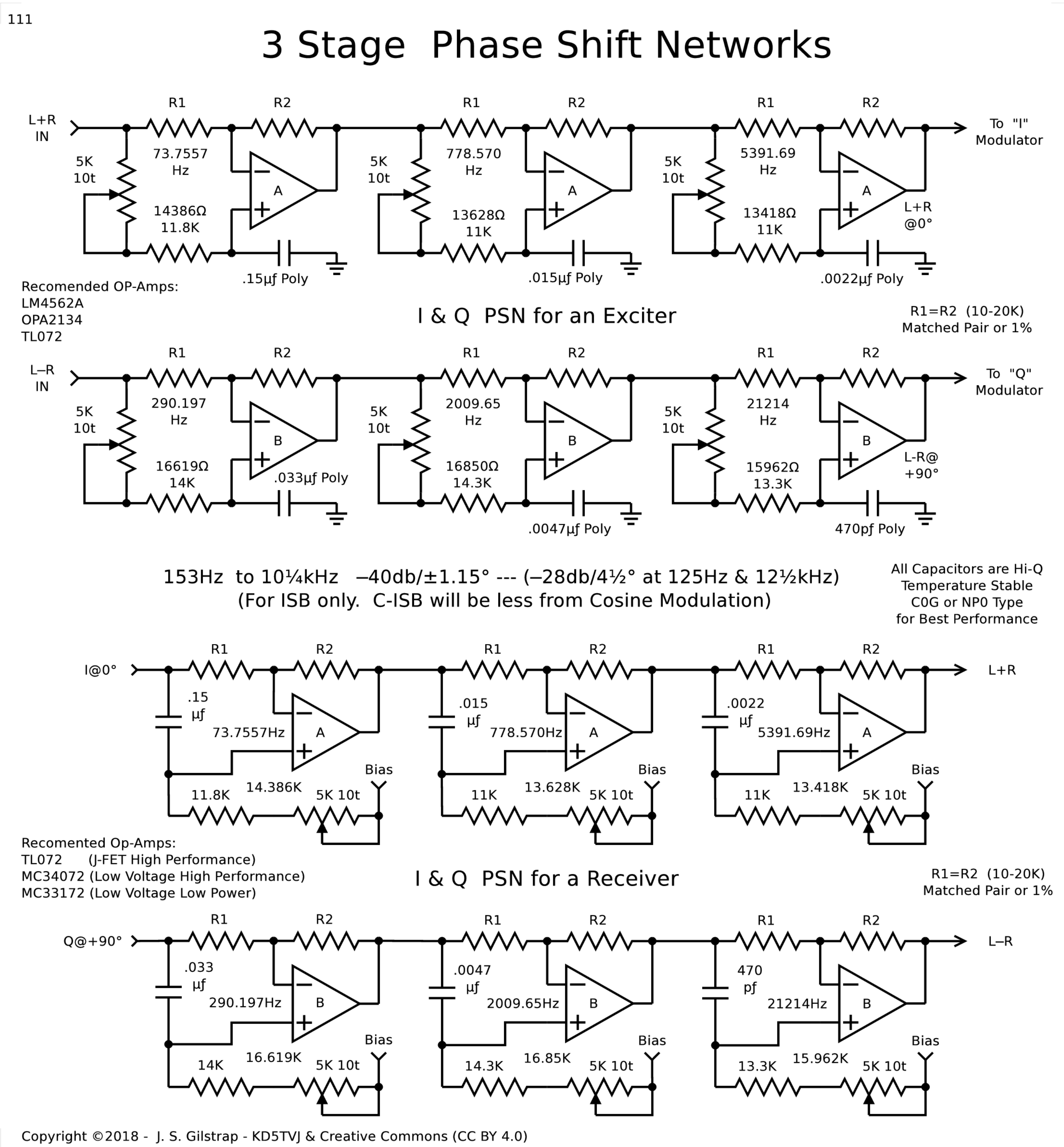




To the right is a schematic for an MC13020P adapter that implements some of these ideas to produce a dynamic result. Pin 5 is the filter pin for the ΔG Cell and its output is inverted, i.e. it goes negative when gain is increased. When the gain is 1 it will never exceed a certain level so this is common level during no cosine modulation. To set this as the VREF for common an envelope detector is used and then buffered with an op-amp. In order to reduce the gain momentarily during noise peaks a varistor (Perkin-Elmer opto-isolator) is used to shunt pin 5 to common by varying amounts. When pin 5 exceeds the adjusted set level the emitter of the NPN transistor limits this to keep the ΔG Cell within the acceptable boundaries but this also clips the modulated gain signal which can also produce audible distortion. This also outputs a current through the collector which is used to activate the opto-isolator. In order to minimize the clipping the open loop gain of the Err Amp is reduced by the varistor. The resistance of the varistor can almost reduce the ΔG Cell down to 1 if necessary if the clipping is hard enough. The collector output current from the NPN is fed into an RC attack/decay filter (tunable) which drives the MPSA64 Darlington PNP and supplies current to the opto-isolator. This setup forms a negative feedback closed-loop path that produces a limiting/'over easy compression' effect on the ΔG Cell modulating signal. An alternate method, shown in version 2, uses a P-channel JFET with a low 'on' resistance as a varistor with the drain connected to the buffered VREF common, the source to pin 5, and the gate to the NPN collector through a resistive divider. This version also features dynamic blend to QAM synchronous detection.

In **Gray** the other optional addition is a 1/Cosθ high pass filter using a 23H inductor. The estimated impedance at pin 5 for these calculations has been assumed to be around 5-10K. This produces a corner frequency of 35–70Hz. Since the **L–R** high pass roll-off is ~100Hz the nominal frequency seen at pin 5 is ~150-200Hz. Definitely anything below 40Hz (station center frequency tolerance being ±20Hz) is caused by co-channel interference and this helps to reduce but not eliminate the effects of this interference on cosine correction. Obviously obtaining a real 23H inductor is almost impossible so it is simulated with an op-amp to create a gyrator. The inductor is AC coupled to pin 5 through a 10µƒ capacitor. In combination with the inductor the notch filter frequency is 10½Hz just above the ~8Hz corner frequency of the PLL loop filter and as the frequency rises the impedance will increase as the high pass corner frequency is approached.

The 1st Gen. MC13020P chip provides enough access to the functions within the chip to convert it to full synchronous QAM detection while also providing a blend to QAM when in C–QUAM mode during marginal reception conditions. As the newer generation chips emerged access to certain functions disappeared. For the 2nd Gen. MC13022 and its AMAX cousin the MC13122 they removed the Err Amp filter pin so this eliminated the feature that could fully disable cosine correction but still provides access to the **I** & **Q** synchronous detection pins. To reduce the effects of platform motion **L**–**R** blend to mono is used. The 3rd Gen. MC13028 only provides the **L** & **R** output pins which eliminates almost all hacking potential. Word on the street has it that a great amount of engineering was done to reduce platform motion compared to the previous generations so I assume that it is doing something more than the **L**–**R** blend to maintain better separation and cosine correction under



marginal conditions. Owners of radios using this chip report platform motion is rarely an issue. Although the internal technical design information on the chip regarding platform motion is not public I wouldn't be surprised if it addresses the interference induced cosine modulation distortion in similar ways. When the PLL mis-tracks and if an error signal can be obtained this also could be used to apply a vector rotation correction to the **I** & **Q** detectors to de-rotate the platform.

C–ISB™ is my adaptation of C–QUAM to produce an ISB system using existing certified broadcast equipment and receiver chip technology. Technically it is still C–QUAM since it is the PSN audio process that causes the signal to produce independent sidebands. Essentially it is ISB generated using audio PSNs and QAM to generate the phase modulation term while the envelope is modulated with **1**+**L**+**R**. Both **L**+**R** & **L**–**R** are passed through the PSNs so both channels receive this process although there is a 90° audio differential offset between the two which is what causes the **L** & **R** channels to independently sideband. The other added benefit of rolling PSNs is that it shifts the harmonics off the peaks of their fundamentals thus reducing peak modulating levels without limiting, akin to Kahn's Symmetra-Peak. Unlike regular C–QUAM the phase modulation produced is symmetrical and remains DC balanced even when fully limited whereas with C-QUAM during heavy single channel modulation **L**–**R** is DC unbalanced and must be cosine corrected before being sent to the PLL loop filter, otherwise PLL mis-tracking will occur. C-ISB can also approach 95% single channel modulation vs 75% before its peak phase deviation exceeds that of C–QUAM. As with Kahn ISB it can also be received with two mono radios slightly detuned to USB & LSB.

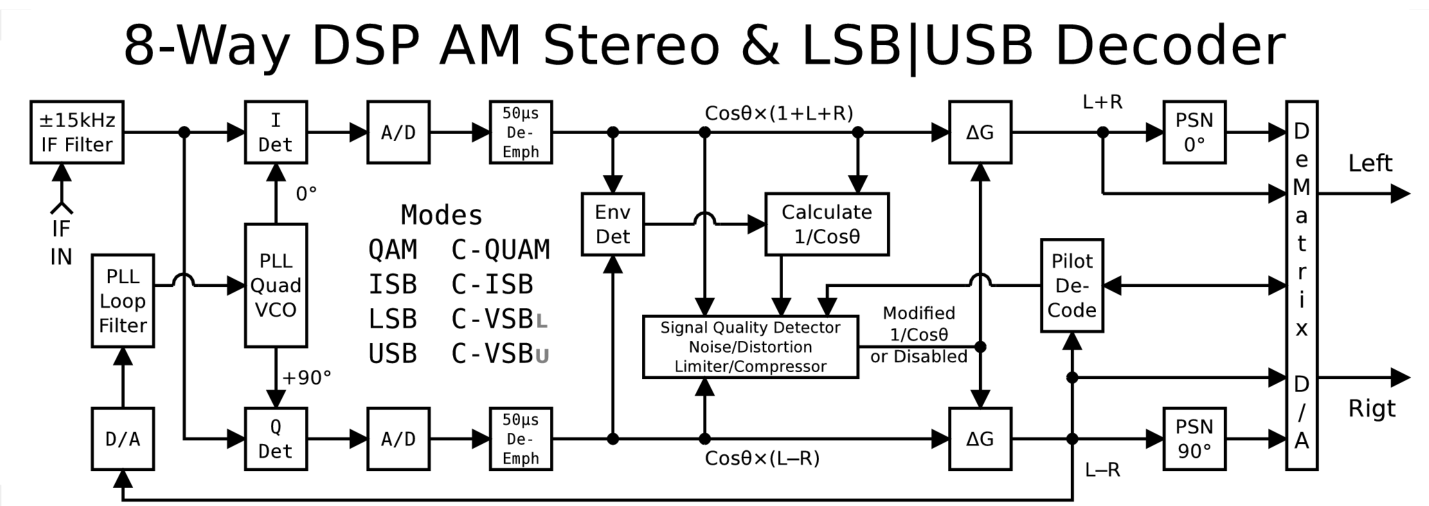
As for the FCC and rules in other countries most audio processing can be done by equipment that does not have the stringent requirements and certifications that are placed on exciters and transmitters. Whether the PSNs' 90° differential offset processing between **L**+**R** & **L**–**R** will pass the litmus test is another question. As long as the audio process does not cause the exciter to exceed its modulating limits is the usual rule and when properly using the PSNs this should be easily accomplished. Reception of C–ISB using a C–QUAM receiver without the PSNs will be distortion free but will produce a unique pseudo stereo phasing effect that is not necessarily objectionable. Providing external PSNs for an existing C–QUAM receiver will properly recover the stereo signal although separation might not be as great as a receiver that has the PSNs built in but better than the two radio approach.

That being said using plain C–QUAM in the SW bands since it is provided for international service and usually under poor sky wave conditions is not optimal. Only under good ground wave reception does C–QUAM preform its best. This is a rare occurrence on the SW bands and few listeners with SW C–QUAM receivers will experience this. These reception issues also plague the upper part of the MW band too. C–QUAM performs best on LW and the lower part of the MW band. Using the C–ISB version of C–QUAM for the SW bands has the potential to produce improved results for the same reasons the Kahn ISB system did for the MW band. It is the distribution of **L** & **R** signals into the separate lower and upper sidebands that is the key as asymmetrical amplitude/phase sideband reception and PLL phase mis-tracking will not reduce separation. This unique arrangement provides several benefits over non ISB setups including regaining the 3dB S/N loss that occurs in C–QUAM. However the best system for SW is Linear ISB generated using QAM and PSNs as this would provide the most robust performance under adverse conditions. However this does not provide envelope compatibility that C–QUAM, Kanh ISB, and Magnavox PMX does but performance using an envelope detector is usually acceptable.

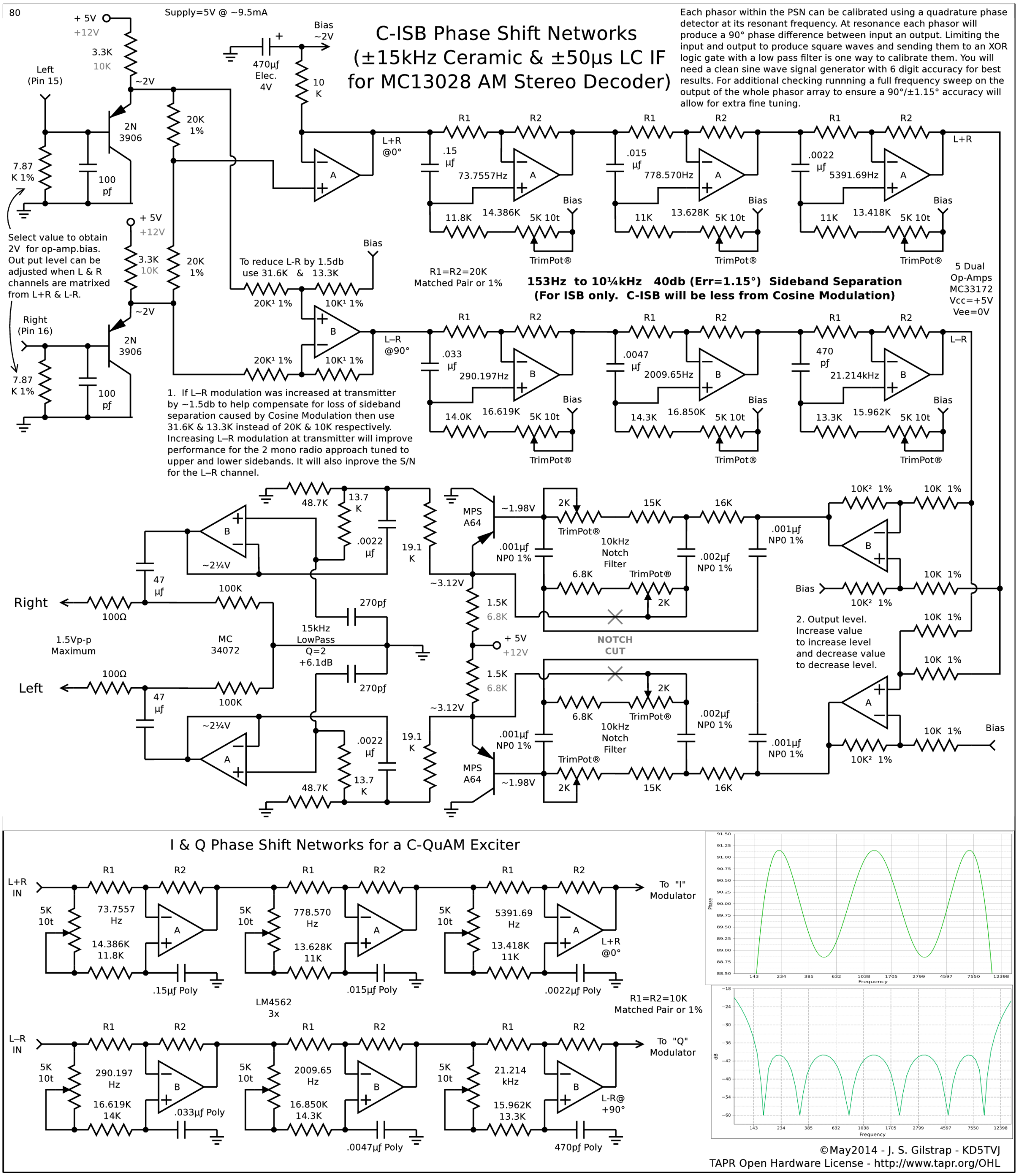
DSP Decoding

I think almost all SDR use QAM **I** & **Q** detectors and since C–QUAM is a modified form of QAM it is not too much of a stretch to add the cosine correction factor to decode C–QUAM. However early analog decoding chips had some shortcomings and could produce erratic results under marginal reception conditions and adapting some chips to detect as pure QAM produces superior results compared to C–QUAM once the noise level rises above a certain level. Except for some of the strongest local stations (50kW) at night all nighttime listening usually sounds better synchronously detected so C–QUAM detected as QAM is less fatiguing under these conditions. It does not take much interference to achieve this point and using a full time synchronous QAM receiver to detect C-QUAM provides surprisingly good results even under excellent reception conditions.

With modified analog decoders C-QUAM detected as QAM will produce a slight loss in separation with a faint white noise type of muddiness in stereo separation on strong **L**–**R** modulation. For most listeners a stereo signal with moderate amount of separation the difference is usually undetectable. That being said using a QAM based SDR should produce very acceptable results without applying cosine correction. Whether to add cosine correction to a QAM receiver is a matter of cost vs signal quality and depends on market size to offset this cost. Except for the most discernible listener the cost usually outweighs the quality improvements for smaller markets. That being said DSP is the perfect platform to design a super C–QUAM decoder on along with decoding other envelope based systems e.g. C–ISB, C–VSB**L**, C–VSB**U**, Kahn ISB, Magnavox PMX, along with regular LSB, USB, QAM, ISB. DSP allows advanced processing to address the shortcomings of envelope detection to produce a quality more akin to synchronous detection. Once market demand increases enough to offset this cost producing a robust decoding process for a SDR multi system decoder will become a reality.



In the image above is a block flow diagram for a DSP QAM centric decoder that through various configurations could decode 8 types of signals. For the most part switching between envelope and synchronous mode and switching the PSNs in or out along with partial filtering of one channel can produce all these modes. For the Kahn and Magnavox systems a slightly different configuration it is possible to decode these systems also. For the cosine corrected systems optimized performance is the focus and controlling/modifying the 1/Cosθ signal is the key. The simplest solution is error reduction/concealment by clamping the 1/Cosθ factor to 1 for short periods of time when distortion caused by interference is produced. Interference usually appears as a large 1/Cosθ correction factor and the peak level of this can be used to calculate a reduction factor to bring it back into range. This is especially needed for C–QUAM but for C–ISB the phase naturally returns to 0° as the (–) trough modulation approaches its minimum. For this situation a dynamic limiter on the 1/Cosθ factor controlled by the (–) trough modulation along with a shaping algorithm could return the factor close to its proper modulation prior to interference. For C–ISB using this method the signal could be distortion corrected close to its original state even during some of the poorest signal conditions. This has a much better potential outcome than what is possible with C–QUAM. Given that even C–QUAM detected as QAM only produces minor noticeable effects C–ISB with this type of correction control could produce near Linear ISB performance under marginal conditions.



The C–ISB™ & C–VSB™ trademarks and the inventions they represent belong to the author of this document. The use of it presented here along with the advanced improvement techniques applied to encode and decode methods is intended for the Open Source community to be used royalty free. Given that most of the patents related to AM Stereo have expired and full adoption of AM Stereo has never reached critical mass I feel this is the best approach to contribute what I have to have the most chance to be initially adopted and to help the cause at promoting AM Stereo to mainstream status. This also applies to the advanced improvement encode and decode techniques applied to C–QUAM presented here.