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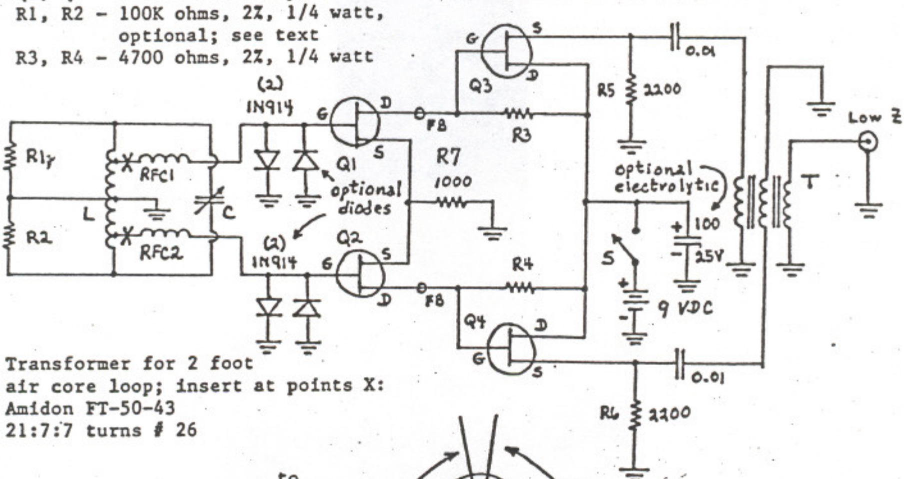
High Performance General Purpose Loop Amp

Dallas Lankford, March 6, 1992

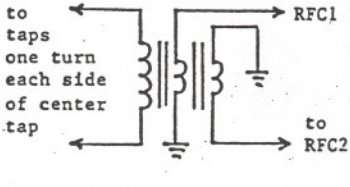
This amp is a further improved variant of the Kolb-Sanserino amp which has been widely used for many years, such as in Radio West's loops, in the RTL-1 remotely tuned loop and other circuits developed by Mark Connelly, and, I have been told, in Palomar Engineers' loops. In my article "What's wrong with present-day loop antennas" in <u>DX News</u> 58, 23 (April 1, 1991) I described some minor improvements to the Kolb-Sanserino amp. However, it took almost another year of development and testing to obtain the major improvements described here.

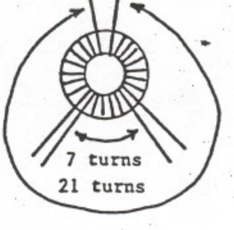
One of the main differences between my amp below and all previous variants of the Kolb-Sanserino amp is that the output of my amp is completely balanced. Balancing the output reduced amp noise (a minor but annoying problem with previous versions), and improved 2nd order IMD performance. It was also found that 2nd order performance was further improved by using FET's for Q3 and Q4 instead of BJT's (which were used in previous versions). My output transformer is homemade, 11 trifilar turns of #26 enameled copped wire on an Amidon FT-50-43 ferrite toroid core. Mark Connelly has reported equivalent performance with a T4-6T-X65 transformer (Mini-Circuits, P.O. Box 350166, Brooklyn, NY 11235-0003).

C - 660 pF; see text
L - see text
Q1, Q2 - MPF102 matched pair
Q3, Q4 - MPF102 matched pair
R1, R2 - 100K ohms, 2%, 1/4 watt, optional; see text
R3, R4 - 4700 ohms, 2%, 1/4 watt
R5, R6 - 2200 ohms, 2%, 1/4 watt
T - 11 trifilar turns #26 enameled copper wire on Amidon FT-50-43
FB - Amidon FB-101-64 ferrite bead



Transformer for 2 foot air core loop; insert at points X:
Amidon FT-50-43
21:7:7 turns # 26





RFC1, RFC2 - 100 μH; 39 turns #26 enameled copper wire on Amidon FT-50-61; omit these chokes when the amp is used with a ferrite rod loop

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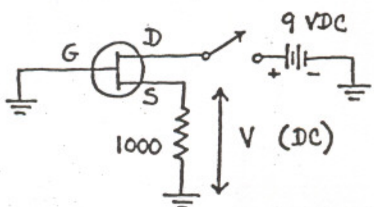
Another major difference between my amp and all previous variants of the Kolb-Sanserino amp are the 100 micro-Henry chokes RFC1 and RFC2. The chokes are not necessary or desirable when the amp is used with a ferrite rod loop; they should be omitted in that case. The chokes are necessary to eliminate 2nd order IMD products due to SW signals when the amp is used with 1 foot or 2 foot air core loops as described below.

The pair of back-to-back diode pairs (4 1N914 diodes) are static protection. I added these to my design recently when Ralph Sanserino told me he occasionally "kills" FET's, especially during dry periods when the Santa Ana winds blow dry desert air across Southern California. Mark Connelly expressed concern that these diodes might cause spurious mixing products, and he has a good point. However, signal levels at the gates of Q1 and Q2 should not be high enough to cause spurious mixing products <u>provided</u> the amp is used correctly. I have observed no spurious mixing products due to the diodes during extensive testing. If any spurious mixing products are observed, you may remove the diodes and replace FET's when you "kill" them.

Amp gain is determined by the 4700 ohm load resistors R3 and R4. For lower gain you may reduce the values of R3 and R4. However, I have found (not surprisingly) that for best strong signal handling performance the amp should be operated at or near maximum gain, and signal levels should be reduced (if necessary) to an appropriate level before the gates of Q1 and Q2.

Resistors R1 and R2 are Q-spoiling resistors for the loop coil. The original Kolb-Sanserino schematic (IRCA reprint A8) included these resistors as optional, but did not discuss their function, or the pros and cons for using them. In my experience, these Q-spoiling resistors are only necessary for previous variants of the Kolb-Sanserino amp which do not have a balanced output, and then only when the amp is used with a ferrite rod loop coil. In that case, without R1 and R2, the loop tuning is asymmetric, which adds some distortion to received audio when the loop is not precisely tuned. This is especially evident on weaker signals as hiss, and is more apparent when the loop is de-tuned to one side of the signal than to the other. With my completely balanced output, the distortion for ferrite rod loops due to this asymmetry is much less apparent, and so the Q-spoiling resistors are not necessary unless you want the best possible audio quality from a received signal. When the Q-spoiling resistors are used, signal levels will be reduced about 6 dB. The Q-spoiling resistors are not necessary or desirable for a 1 foot or 2 foot air core loop.



Q1 and Q2 should be matched pairs of MPF102's, and Q3 amd Q4 should be matched pairs of MPF102's. It is not necessary or desirable that all 4 FET's be matched. The best way I know to match FET's is due to Kolb and Sanserino, and is shown at left. Measure the DC voltage across a 1000 ohm source resistor as shown, and select pairs of FET's with measured V's within 2%. You'll probably need at least 10 MPF102's to get two matched pairs. I use a Radio Shack or similar proto board to breadboard the circuit. FET's can be plugged into and removed from the proto board quickly.

The 660 pF air variable capacitor is available from Antique Electronic Supply, 6221 S. Maple Ave., Tempe, AZ 85263, (602) 820-5411, catalog no. CV-240, $4.65 each. It is two sections, 320 pF and 345 pF, which are wired in parallel.

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As I pointed out previously, you will have to degrease and regrease the bearings because the original grease has dried out, causing stiff bumpy rotation of the shaft.

The main reason this amp was developed was for use with a 1 foot air core MW loop. My 1 foot square loop coil is 22 turns of #18 bare stranded (7x22) copper wire, center tapped, about 1/4 inch spacing between turns, 2 inch spacing between 11 turn halves, with taps 1 turn each side of center tap. The tuning range is about 485 KHz to 2150 KHz. Ralph told me he has constructed a similar 15 inch square air core MW loop with the amp connected across the entire loop coil, but I have recommended that he not do that because the resulting signal levels will be higher than needed and the strong signal handling performance will be degraded.

This amp can be used with many ferrite rod loops, especially those built by Ralph Sanserino and sold by Radio West. For most ferrite rod loops the amp is connected across the entire loop coil, and, as I said above, RFC1 and RFC2 are omitted. For ferrite rod loops, R1 and R2 are optional; see my previous remarks. I have used a homemade version of Ralph's ferrite rod loop which consists of 4 rods, bundled and overlapped, 3/8 inch diameter by 8 inches long rods, initial permeability 125, 26 turns of #22 enameled copper wire, center tapped. It is an excellent amplified MW loop.

This amp can also be used with a 2 foot air core MW loop. In that case a matching transformer should be inserted at the points marked X as shown on the schematic above. For details of the 2 foot air core loop coil you should consult my previous article, "High dynamic range balun loops, " which appeared in DX News 58, 23 (April 1, 1991). The IMD performance of this amp and matching transformer seems to be about as good as the high dynamic range balun loop amp which was originally used with my 2 foot air core MW loop. Unlike the balun loop amp, the gain of this amp does not depend on the load it sees. Thus it would appear to be an improvement over the balun loop amp.

As I have said many times before, the most frequent defect of many previous amplified loop antennas is excessively high signal levels. When excessively high signal levels are applied to the input of an amp, spurious responses are often generated in the amp. And when excessively high signal levels are output from an amplified loop, the receiver dynamic range is degraded. In both cases the weak DX you want to hear may be covered up by spurious responses. Yet many DXers continue to degrade the performance of their receiving systems with amplified loop antennas which have excessive signal levels.

Tapping down on the 1 foot loop coil, as described above, illustrates the preferred solution to the excessive signal level problem for amplified loops with high input impedance amps. The signal levels input to the amp are reduced before the signals arrive at the amp. Sometimes a loop coil does not have enough turns to permit the signal levels to be reduced to a suitably low level. For example, a balanced 2 foot air core loop for the MW band typically has 14 turns, center tapped. Thus the minimum signal levels which can be obtained directly from a 2 foot air core MW loop are obtained by taps one turn each side of center tap. However, if my amp is connected directly to those two taps, signal levels are about 10 dB higher than needed. (In the past, high gain, high input impedance amps were connected across the entire loop coil, which resulted in signal levels 20 dB or more higher than needed!) This problem could be solved by reducing

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amp gain by 10 dB. However, signal levels at the input to the amp would still be 10 dB higher than needed. For best strong signal handling performance I have found that many of these kinds of amps should be operated at or near maximum gain, and the input signal levels to the amp should be reduced by an appropriate amount, in this case 10 dB. The matching transformer for the 2 foor air core MW loop reduces the output voltage from the coil by a factor of 3, which is equivalent to a 10 dB reduction in signal levels input to the amp. In theory this improves the effective 2nd order intercept of the system by 10 dB, and improves the effective 3rd order intercept of the system by 20 dB.

Spurious responses observed from an amplified, balanced, air core, MW loop antenna are seldom the result of inadequate 3rd order IMD performance. As a matter of fact, I have never observed any 3rd order IMD products from an amplified MW loop during on-the-air use. Of course, 3rd order products can be generated and observed using signal generators in a laboratory setting. The same cannot be said for 2nd order IMD products. If you observe any IMD products from an amplified MW loop during on-the-air use, you can be virtually certain they are 2nd order products. Moreover, the 2nd order products you hear, if your amplified loop has any, are usually due to a frequency difference $f_1 - f_2$ of two SW signals of frequencies f_1 and f_2. For example, if you connect my amp directly to a 2 foot air core MW loop (without the 3:1 turns ratio matching transformer), and do not use the 100 micro-Henry chokes RFC1 and RFC2, or if you use any similar high gain, high input impedance amp, then almost every evening for the first several hours after local sunset you may observe some (and occasionally numerous) SW 2nd order IMD products as you tune your receiver between 1.6 and 2.0 MHz, especially with the receiver BFO turned on, and with the loop detuned (say, to around 500 KHz). Even with the loop tuned to the received frequency (in the 1.6 to 2.0 MHz range) you may still observe SW 2nd order IMD products near the ambient noise floor on a quiet night.

Balanced, amplified, MW air core loops are susceptible to SW 2nd order IMD products because they are actually quite good antennas for the SW frequencies above about 5 MHz. If you have a 2 foot or larger balanced, amplified, MW air core loop, turn the amp on and tune your receiver between 6 and 16 MHz during the early evening hours. Unless your amp is my balun amp, or my amp above with chokes RFC1 and RFC2, you will find that signal levels above about 9 MHz are almost as high as with a full size outdoor LW antenna. In effect, your loop is a broadband SW antenna, and you amp is a broadband amp for SW signals above about 5 MHz. Even the best amplifiers do not have high enough 2nd order intercepts to prevent 2nd order IMD products from being observed at medium frequencies (on quiet afternoons and evenings) when the amp is used with a balanced, air core MW loop. Fortunately, I discovered a simple solution for this problem some time ago when I developed the balun amp. A 100 micro-Henry choke added at the appropriate point in the balun amp, or a pair of 100 micro-Henry chokes added at the appropriate points in my variant of the Kolb-Sanserino amp pass MW signals without loss, but reduce SW signal levels, especially those above 9 MHz, up to 20 dB or more. Thus SW 2nd order IMD products are reduced up to 20 dB or more, and well below the threshold of detectability.

Perhaps I should add that if you live an an urban area with high levels of ambient man-made noise, then you may seldom hear the SW 2nd order IMD products discussed above. For example, in Riverside, CA Ralph Sanserino normally has about 20 dB of ambient man-made noise when using one of the loops described above with an R-390A, while I normally have 0 dB or less ambient man-made noise. With previous versions of the Kolb-Sanserino amp (sans chokes, and not tapped down on the loop coil), SW 2nd order IMD products are seldom as strong as 10 dB

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and so Ralph has never observed them. Similarly, many DXers in noisy urban areas may never hear these SW 2nd order IMD products. However, it appears that the problem of SW 2nd order IMD products is not entirely unheard of. In a recent issue of DX News the IDXD editor discussed several SW "images" which had been reported to IDXD and another SW "image" which he had observed recently. It appears they observed SW 2nd order IMD products which originated in their amplified MW loop antennas.

Some variation in components for my amp is permissible. For example, Mark Connelly suggested using a Mini-Circuits T4-6T-X65 transformer instead of my homemade transformer T. While I was typing this article I received one of these MC transformers from Mark. I checked it out and found no differences in signal levels or IMD performance. So the MC transformer would appear to be a winner because it saves time making a transformer. The chokes RFC1 and RFC2 were homemade because the chokes I had been using ("high reliability" Mouser 43HH104) proved unreliable. Ordinary handling can cause them to develop an internal open circuit. Perhaps some other commercial choke (maybe Mouser 434-1120-101L) would be satisfactory. In a similar amp, Alan Merriman reported that a Radio Shack 100 micro-Henry choke caused bad spurious responses. Using different FET's is not a good idea unless you are willing and able to do extensive testing, and you have extremely low levels of ambient man-made noise. For example, I tried U310's in place of the MPF102's after someone suggested them. The U310's gave greater gain, as I was told, but they also generated considerably more amp noise. The additional amp noise was about equal to the additional gain. When the load resistors were adjusted to equalize amp noise, there was no difference in amp gain. So there is no advantage to using U310's in place of MPF102's. These experiences illustrate the importance of testing if you make any component changes.

I would like to express my appreciation to Mark Connelly and Ralph Sanserino for comments and suggestions relating to this article and the amp design. For example, Ralph recently asked me to clarify how ambient man-made noise could give a carrier meter reading of less than 0 dB on an R-390A. Of course, Ralph is right. The R-390A carrier meter (when properly adjusted) does not read below 0 dB. What I meant was that because an R-390A has delayed AGC, there is 20 dB or more "headroom" above the R-390A noise floor and below the point at which the carrier meter begins to move. On extremely quiet days at my location the ambient man-made noise floor in the MW band is (I estimate) about 5 to 10 dB below 0 dB on the R-390A meter using any of my standardized antennas. That is what I meant when I said I have less than 0 dB of man-made noise on some occasions. Although I can't find the letter or article where Mark mentioned it, I recall Mark writing that he has experienced SW second order intermodulation distortion when using this amp with a ferrite rod loop. So my suggestion above to omit the 100 microHenry chokes when using the amp with a ferrite rod loop should be ignored, and you should use the 100 microHenry chokes with all MW loops. It never occurred to me that DXers closer to Europe, like Mark, would experience SW second order intermodulation products with loops which would be free of spurious responses at my location where SW signal levels are lower. But apparently that is indeed the case.

Finally, a few words are in order regarding which kind of loop you should build or buy - ferrite rod(s) or air core. Recently while testing the AGC mod I performed on Russell Scotka's NRD-525, I discovered, much to my surprise, that my two foot air core loop was much less susceptible to the NRD-525 display noise than my ferrite rod loop. I do not know whether this is also true for a one foot air core loop because I did not have one prototyped at the time. I have no explanation for this strange discovery, but it should be studied further.

For an NRD-525, display noise was reduced below ambient man-made noise at my location (which is considerably lower than ambient man-made noise in typical urban locations) when the two foot air core loop was moved three feet or more away from the NRD-525. With the two foot air core loop three or four feet away from the NRD-525 it was not awkward or difficult to operate the loop and receiver simultaneously. In fact, it would be inconvenient to have the loop much closer to the receiver. If a one foot air core loop is equally less susceptible to NRD-525 display noise than a ferrite rod loop, and if air core loops are equally less susceptible to display noise of other solid state receivers than a ferrite rod loop, then air core loops would clearly be the MW band loops of choice. Increased prices of ferrite rods, and inherently limited sensitivity of ferrite rod loops are other reasons which make air core loops more attractive than ferrite rod loops.