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Drake R8: Increased Dynamic Range, Mod 2

Dallas Lankford, 3 III 94

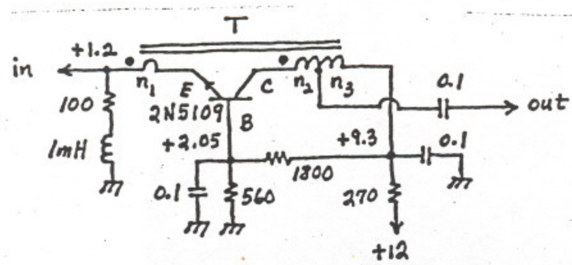
In my DX News 60, No. 27 - June 28, 1993 article, "Drake R8: Increased dynamic range," I described a simple method of increasing the dynamic range of the R8. Subsequently, I discovered that the improvement I reported may not be so dramatic for some R8's when I bought another R8 RF PC board to have on hand for "before-after" comparisons. This new (unmodified) RF board had substantially better 3rd order intercepts than my original RF board before I modified it, namely about -2 dBm with preamp on, and +10 dBm with preamp off. To satisfy my curiosity, I restored my modified RF board to original, but with a new SBL-3 mixer and new J310 FET, and measured the intercepts. They were about -2 dBm and +10 dBm respectively for preamp on and off, about the same as for the newly arrived RF board. Apparently the SBL-3 mixer or J310 FET or both were defective in my original R8. Consequently, I recommend against doing that mod because the improvement in dynamic range over an unmodified R8 does not justify the effort, assuming that your R8 is not defective, as mine apparently was originally.

The simplest way to improve the R8 out-of-band dynamic range is to use a low-gain tuned preselector. I have not tried this approach myself, but I have been told by several R8 owners that it is a simple and effective solution for the R8 dynamic range problems. What preselector should you use? Again, I have no first hand experience with tuned preamps. The MFJ-1020A indoor active antenna might be suitable; it has been been rated a excellent when used as a preselector in some reviews, though poor as an active antenna. It tunes 0.3 - 30 MHz in 5 bands (the MW band is split into 0.3 - 0.7 and 0.7 - 1.6 MHz), and sells for $79.95. MFJ also sells an MFJ-956 SW/MW/LW preselector/tuner for $39.95 which might be suitable. It is apparently passive (no amp), and tunes 0.15 - 30 MHz in 4 bands.

A tuned preselector improves dynamic range by reducing the signal levels of the offending stations. Thus, the preselector approach is effective against signals 100 KHz or so away from the desired signal in the MW band, and several 100 KHz away from the desired signal in the SW band. A preselector is not effective against nearby signals, and does not improve the close-in dynamic range.

Despite the disappointment of my first effort, I have remained interested in subatantially improving the R8 dynamic range. The MiniCircuits data book suggests that the SBL-3 mixer should be capable of considerably higher 3rd order intercept than the R8 achieved, namely about +18 dBm (with preamp off). The amount of improvement with preamp on depends on preamp gain and other factors.

My second attempt at improving the R8 dynamic range began with the preamp. After extensive measurements, I had concluded that the R8 preamp had too much gain, and it was too noisy. The original RF preamp was removed and replaced with so-called noiseless (transformer feedback) amplifier set up for 9.5 dB gain. A schematic of this preamp is given below.



T = 2:10:6 ($n_1:n_2:n_3$) turns #24 on Amidon FT-50-75 wrapped with Teflon tape

Measured preamp-on sensitivity in the 6 KHz BW, AM mode, 400 Hz modulated 50%, with the shield described in my article (same DX News above), "Drake R8: Type B spurs elimination," was 0.35 microvolts for a 10 dB S+N/N at 1.8 MHz. Without the shield, preamp-on sensitivity was 0.55 microvolts.

Next, the J310 1st 45 MHz IF amp was replaced with a noiseless (transformer) feedback amp set up for 12 dB gain, followed by a diplexer, followed by a 9:1 broadband step-up transformer (the 1st 45 MHz IF transformer was removed). A schematic of this mod is given below.

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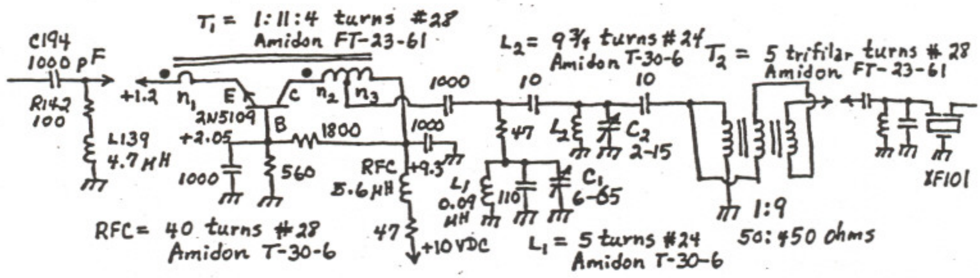
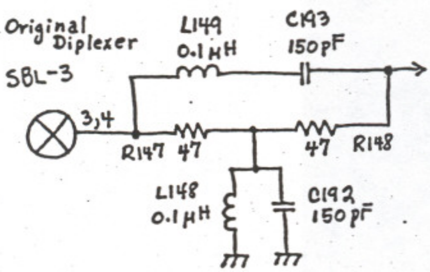
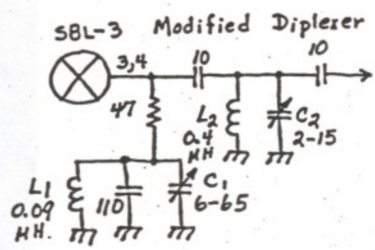


The exact circuit of the 45 MHz crystal filter (XF101 and preceeding parts) is unknown. The parts on both of my RF boards do not agree with the R8 service manual schematic. I was told by a Drake engineer that the input impedance of the crystal filter is 500 ohms real, so I used a 1:9 step up transformer, which is a reasonably good match. I also used C194, R142, and L139 from the original R8 1st 45 MHz IF amp to save space. RFC is probably not necessary because there is already good decoupling of the +10 VDC line on the R8 PC board at the 1st 45 MHz IF amp, but I wanted to be sure that I had the 2N5109 feedback amp well isolated from the DC line.

The 3rd order input intercept, ICP3, of the original 1st 45 MHz IF amp (tones injected at P104) was +18 dBm. The ICP3 of the above modified 1st 45 MHz IF amp was +29.5 dBm. External stand-alone measurements of a push-pull version of this amp have shown that it is capable of +40.5 dBm ICP3 when it is terminated properly, so perhaps some further improvement is possible for the ICP3 of the 1st 45 MHz IF amp.

The last step in the modification was to replace the R8 diplexer following the SBL-3 1st mixer. The original diplexer is given below on the left, and the new diplexer is given below on the right.





Several types of diplexers were tried following the 1st mixer. The one above, derived from a 9 MHz diplexer in Fig. 11 of Chapter 6 of Solid State Design by W. Hayward and D. DeMaw, gave higher ICP3 and was easier to tune than the others. Practically everyone agrees that the 2nd harmonic termination (L1,110 pF, C1) should have a high C/L ratio, and that the ratio should be about what I used. However, there does not seem to be general agreement on how to implement the signal path part of the diplexer. So perhaps further improvement is possible in this part.

All tuned circuits of the diplexers should be tuned to resonance. This is easy to do for the signal path part (L2,C2) because there is a very pronounced peak in signal level when C2 is adjusted (with a CW signal generator connected to the R8 antenna input terminal). A word of caution is in order concerning the signal path tuned circuit, L2,C2. The inductor L2 is about 0.4 microHenrys, which is tuned to resonance at 45 MHz with about 30 pF of capacitance. Due to the nature of the capacitive coupled circuit, the coupling capacitors are added to C2; they are part of the resonating capacitance. When distributed capacitance of L2 is included together with stray capacitance, very little additional capacitance is need to tune the circuit to resonance. With the turns spaced evenly around the toroid (L2), resonance was obtained with about 5 or 6 pF from C2. The point is that there may be enough variation in T-30-6 toroids to require addition or subtraction of a turn to or from L2.

Final adjustment of the diplexers may be done with a two tone IMD measurement system with two tones of about -10 dBm spaced about 40 KHz apart in the 1.6 to 2.0 MHz range. However, a high dynamic range IMD measurement system is required for this approach. A better approach is to adjust C2 of the mixer diplexer for minimum intermodulation distortion on some MW band distortion product in the 1.8 to 2.0 MHz range with the preamp turned on. With this

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approach, and the R8 in CW mode, on a quiet morning, the IMD3 on 1.85 MHz due to KRUS and KWKH (2x1.49 - 1.13) can be completely eliminated. Other IMD3 which I used to hear at night (from many sources) are now completely gone from the 1.8 - 2.0 MHz range.

With the diplexers adjusted as described above, and tones spaced about 40 KHz apart in the 1.6 to 2.0 MHz range, preamp-off ICP3 was about +20 dBm, and preamp-on ICP3 was about +10 dBm. These ICP3 values hold up to about 10 MHz, and then begin to fall off slowly to about +13 dBm preamp-off and about +6 dBm preamp-on at 15 MHz. For comparison, using my unmodified RF PC board, I got +12 dBm preamp-off and -2 dBm preamp-on ICP3 at 15 MHz. While making these measurements, I observed that there was considerable variation in ICP3 between the 2xf1 - f2 and 2xf2 - f1 IMD3, so I took the worst of the two ICP3's for the values above.

The above mods also improve the 2nd order performance of an R8. For example, the preamp-off ICP2 of a stock R8 is about +40 dBm at 510 KHz for tones at 980 and 1490 KHz. The corresponding ICP2 of a modified R8 is about +53 dBm, which is about what an SBL-3 mixer is capable of when properly terminated according to MiniCircuits data. The preamp-on ICP2 of a modified R8 at 510 KHz due to 980 and 1490 KHz tones is about +43 dBm.

Although these mods have made the R8 3rd order intercepts with preamp-on about as good as an unmodified R8 with preamp-off below about 10 MHz, I have changed my mind about rewiring the R8 to leave the preamp permanently on, as described in my previous article. A better solution, which I have not done yet, is to install an on-off switch on the rear panel so that the preamp can be switched between always-on and R8-original. This should be implemented so that the switch can be unplugged from the RF PC board to facilitate easy removal of the PC board. The best solution, of course, would be for Drake to change the software so that the preamp can be enabled below 1.8 MHz.

As much as 6 dB additional increase in the 1st mixer 3rd order intercept might be possible with square wave local oscillator drive as suggested by technical correspondence, page 43, QST, October 1988. However, the feasibility of changing the R8 1st LO to square wave drive has not been established. A push-pull 1st 45 MHz IF amp would probably be required in this case.

The discussions above were written on 3 III 94 and revised on 8 III 94. At about the same time, the work described in the following addendums was begun. At first, the subjects of increasing R8 dynamic range and increasing R8 50 KHz IF image rejection seemed unrelated, and I hesitated to include the two topics together in a single article. But as you will understand by the end of this article, the two apparently different topics are related because the R8 50 KHz IF image rejection mod continued to evolve, and finally interfaced with the R8 increased dynamic range mod 2. I do not know whether a variation of the 50 KHz IF image rejection mod will work stand-alone, i.e., without modifying the 1st 45 MHz IF amp. The original R8 1st 45 MHz IF amp has a higher impedance load (the tuned LC circuit for the J-310 FET), and higher impedance circuits are more prone to RF leakage than lower impedance circuits. My best guess is that the 50 KHz IF image rejection mod would not be as effective if used with the original R8 1st 45 MHz IF amp.

Addendum, 13 III 94

After completing the mods described above, I turned my attention to one of the remaining R8 defects, inadequate image rejection. Several R8 reviewers have rated the typically 80 dB image rejection of the R8 (for the 50 KHz IF) as excellent, but that really is not the case at lower frequencies where there are exceptionally strong signals (in the MW band, and in some of the lower SW bands). A really outstanding receiver, like the R-390A or NRD-525, has 100 dB image rejection in the MW band, and the image rejection tends to fall off slowly as frequency increases. For example, the 455 KHz image rejection of my NRD-525 is about 100 dB for the 580 KHz image of 1490 KHz, about 90 dB for the 1090 KHz image of 2000 KHz, about 86 dB for the 9.090 MHz image of 10.000 MHz, and about 74 dB for the 19.090 MHz image of 20.000 MHz. For my R-390A, the 455 KHz image rejection is in excess of 100 dB at all frequencies, the variable 17.5 - 25 MHz IF image rejection is in excess of 100 dB at all frequencies for which it is used (0.5-8.0 MHz tuning range), and the 2-3 MHz variable IF image rejection varies from 90 dB at 10 MHz to 76 dB at 20 MHz.

The obvious soultion for the inadequate R8 image rejection is to add additional filtering in the 45 MHz 1st IF signal path. But I had tried that before, without success. Eventually it dawned on me to do what I have done before to test for signal leakage when implementing filter mods, break the signal path. And I got lucky and broke the signal path at C176 and C175 (by removing them); with the path broken at this point, the signal was down a mere 40 dB. The indication was that the input circuit of the image reject circuit was acting as an antenna. To test that hypothesis, I removed the input part of the image reject circuit R140, L146, C139, L147, C188, C190, C191, L156, L157, and C208; see the schematic below. With these parts removed, the signal was down in excess of 100 dB. My initial inclination was to rebuild the image reject input circuit in a small RF tight box and reinstall it. Before I started on that project, I decided to remove the remaining parts fo the image reject circuit just to see how bad the bare-bones image rejection really was. So I took out R160, R161, R162, C232, L159, L170, C242, C233, C241, L171, L172, C234, and R155, and installed jumpers to enable one of the SBL-1X 2nd mixers.

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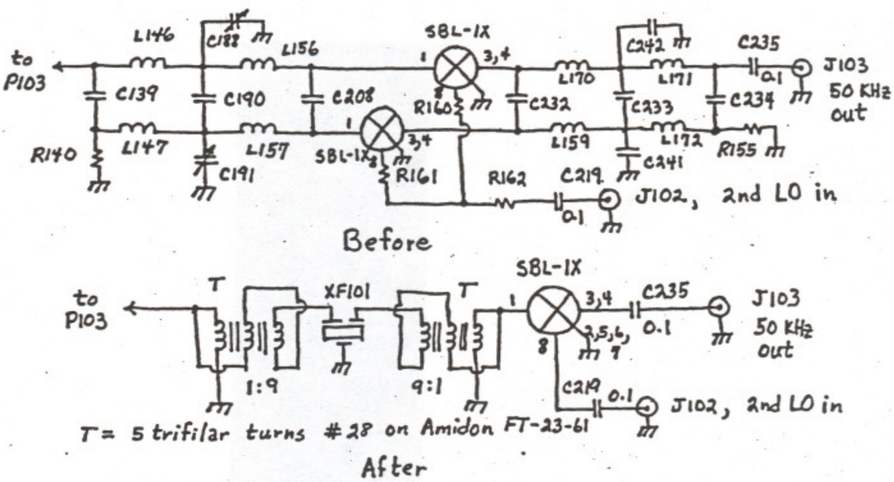
You can imagine my surprise when the image rejection improved with the image reject circuit removed, to about 90 dB.

Next, I fabricated a small PC board adapter with two impedance matching transformers and one XF101 45 MHz crystal filter and installed the adapter in some convenient holes formerly occupied by the image reject input circuit. The image rejection went up to just a tad over 100 dB. The completed mod is shown below.

At first I mistakenly concluded that the image reject circuit of the R8 did not work. To test this hypothesis, I removed the image reject circuit from an otherwise unmodified R8 RF PC board which had 80 dB image rejection before removing the image reject circuit. After the circuit was removed, the image rejection dropped to 54 dB. My present hypothesis is that the changes I made to the 1st mixer diplexer and 1st 45 MHz IF amplifier, as described above, are responsible for the improved 50 KHz image rejection. To test this hypothesis, I will need to implement those changes on this second RF PC board. Unfortunately, at present I am without some of the parts need to do those changes.



Unintentionally, two crucial aspects of the image reject mod were omitted from the discussion. I had rewound L128 (the last 45 MHz IF transformer) with 9 3/4 turns #24 close spaced at the bottom (when mounted on the PC board) of the T-30-10(I think) toroid, and I had replaced C174 by a 6-60 pF ceramic trimmer (Mouser 24AA024, modified by trimming off parts of the mounting lugs and reworking the trimmed lugs with an India stone so that the lugs would fit properly in the PC board holes). I discovered these omissions while modifying the "new" PC board. The C174 change is probably not necessary, but the Mouser 24AA024 trimmers seem like higher quality trimmers than those used in the R8. When mounting the trimmer, be sure to mount the "ground" lug in the "ground" PC board hole. Drake production line workers did not seem to pay much attention to details like this; the original C174 was mounted incorrectly.

With the IF amp change, but L128 unchanged, image rejection was improved from about 54 dB to about 66 dB. After L128 was changed as described above, image rejection improved to 80 dB.

The "new" RF PC board I received from Drake was missing the small shield which covers the bottom of the crystal filter XF-101/XF-100. I don't know if this is a production change, or if I was shipped an imcomplete RF board. In any case, omission of the shield degrades potential image rejection. I fabricated a similar shield out of copper plate and installed it under tension, without soldering it in place. The image rejection improved to 86 dB.

All of the above image rejection values are without the crystal filter installed at the input to the SBL-1X 2nd mixer. With the additional crystal filter, image rejection was about 100 dB, maybe a tad less.

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It would appear that the primary cause of poor R8 image rejection is due to radiation from the high Q inductors of the 45 MHz IF transformers L140 and L128. My mod eliminated L140 altogether. Examination of the PC board in the vicinity of L128 suggests that extending the ground plane under the shield, and using a solid shield (no hole in the top) might improve image rejection further. Also, surrounding the input and output traces of the crystal filter XF-101/XF-100 with ground plane might improve image rejection further, and a more complete shield across the bottom of the filter might also help. This evening I have been eyeing L138, the inductor of the 2nd 45 MHz IF transformer and wondering if rewinding it might further increase image rejection.

L128 does not actually have to be rewound because it comes with 11 3/4 turns #24, spaced evenly around the entire toroid. You merely remove two turns, adjust the spacing to close-spaced, trim and re-tin the winding ends, and reinstall it.

All of the circuits above were fabricated on small PC adapter boards and mounted as close to the R8 PC board as possible. The ground lead and high impedance lead of T2 of the 2N5109 IF amp were mounted on the R8 PC board in existing holes for L140, and the low impedance lead was connected to the nearby adapter board. No special shielding or layout was used for the crystal filter (T/XF-101/T) at the input to the 2nd mixer SBL-1X, though the input transformer, crystal filter, and output transformer were laid out in a straight line, and very short traces and adapter leads were used.

I don't know if you can buy a single XF101 filter from Drake. When I inquired about the filter, I was told only that a crystal filter set, consisting of a matched pair of 45 MHz filters and a 10.245 MHz filter (for FM) could be purchased. The price last year was about $25. You should inquire about current price and availability.

<u>Addendum 2 VI 94</u>

After further experiments with the R8 image rejection, and further thought about the nature of the problem, I have decided that the best way to proceed is to remove the undocumented surface mount components associated with the two-filter 45 MHz crystal filter, remove one of the filters, and use the removed filter at the input to the 2nd mixer (after removing the image reject circuit as described above). With this approach, the image rejection is about 100 dB, which is about as good as can be achieved with any of the approaches I tried. This approach obviates buying another 45 MHz filter from Drake. The original two-filter 45 MHz crystal filter circuit in an unmodified R8 simply seems like a bad idea to me because the amount of image rejection from that circuit depends on the geometry of the PC board layout and the geometry of the IF transformer windings, which in turn determines the amount of phase cancellation, and thus the amount of image rejection. If my analysis of the situation is correct, it is a very unsatisfactory situation, and there is no need for two filters where they were used. My present modification to the original 45 MHz crystal filter is shown below.