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The Ultimate Homebrew Receiver? Not Quite!

In the September 24, 1983 DXM, the technical column featured an article entitled "Designing and Building Your Own MW Receiver" (also page 109 in the Technical Guide, 2nd edition; also reprint M39). I have designed and built two MW receivers in the last ten years; a simple one was described in the March 7, 1981 DXM (reprint M24). The other was more or less completed in January of 1987, and I'm finally going to describe it, though only in block diagram form to save valuable DXM space.

Why has it taken 3½ years to write this article? Initially, I felt that my receiver was quite satisfactory, but that several improvements could be made, so I decided to wait until these improvements were put in place. Since then, real life has reared its ugly head (family, mortgage etc.--you can fill in the details), and I've been lucky to DX in my spare time, let alone design and build, so the receiver is as ugly and unimproved as ever. Time constraints have also meant little time for writing articles, as the infrequency of the technical column can attest to. One positive result of these delays is that the present design has been in use at various locations, using various antennas, for all this time. I've probably found most of the bugs, even if they haven't been removed.

Enough personal details...on with the show. I'll toss the block diagram at you right away. ~~(see top of the next page)~~ Each block in the diagram has indicated in parentheses which active or distinctive passive elements are used in that block. The dotted line between sections indicates different shielded boxes within the receiver. Each box is connected to the next box using BNC connectors and RG-58 coax. A modular receiver such as this, with 50 ohm inputs and outputs allows easy experimentation on different sections of the receiver.

Following the same outline found in "Designing and Building Your Own MW Receiver", I'll go through the diagram from the headphones back towards the antenna, addressing each block along the way. Having the previous article to hand will probably help you to make sense of this one.

The set uses a supply of 12 volts, and its total draw does not exceed 250 mA. On DXpeditions, the current is supplied by a 12 volt storage battery, but in more civilized locations, a 12V 0.5A DC power supply built into the receiver case supplies the necessary current.

A stereo amplifier chip is used in the audio section of the receiver. Although this chip can supply 2.5 watts per channel, I never use much more than a fraction of a watt to drive my stereo headphones. At home, I can use speakers driven by a separate 7 watt stereo amp which takes its input from before the LM377 chip; I choose not to drive speakers with the LM377 to keep current consumption (and resultant heating) within the set to a minimum. Why a stereo amplifier? At some point in the future, I want to attempt diversity reception, i.e. upper sideband to one ear, lower sideband to the other ear, by either using USB/LSB IF filters, or through an advanced form of synchronous detection. Such reception will require a stereo amplifier.

My synchronous detector is the simple variety, based on an XR2228 analog multiplier IC. A sample of the 455 kHz IF output is amplified so much that it becomes a heavily clipped wave which matches the signal carrier in both frequency and phase. This square wave is mixed with the unprocessed IF amplifier output to deliver the audio which was initially modulated onto the signal carrier. This type of detector is easier to build and to use than a PLL synchronous detector and deals better with weak signals than some PLL designs. I feel that the quality of the audio derived from this circuit is superior to that obtained from envelope detectors, though I have never made a formal detector comparison.

The amplified input of the XR2228 detector can also be fed by a crystal controlled 455 kHz BFO rather than by the received signal. This "spots" carriers even when the overall signal is too weak or too buried by splatter to deliver readable audio. Crystal control of this circuit is an example of overdesigning, but it does enable me to spot carriers to the nearest 100 Hz on the frequency display. Crystal control will also be necessary the day I start to delve into USB/LSB diversity reception.

The MuRata CFG-455I filter (4 kHz minimum passband at -6 dB) was placed before the detector to eliminate any out of passband intermodulation distortion or wideband noise which may be generated in the IF amplifier. This is a technique much used by radio amateurs in their receiver design, and is probably worth the few extra dollars, even though I have not seriously tested its efficacy.

As mentioned in my previous article, the bulk of amplification in a well designed receiver takes place in the IF stages, and that is the case in my present receiver. Two CA3028 differential amplifier ICs and a 2N3904 transistor provide about 35 dB of gain, though they can provide up to 75 dB according to the spec sheets. The rest of the components indicated in the IF amplifier block constitute the AGC circuit. More IF gain is provided earlier in the IF strip, as can be seen in the diagram, but that is not AGC controlled. The IF amp/AGC block is pretty much a direct copy of what appears in Solid State Design for the Radio Amateur and other ARRL publications, though I did monkey about with IF transformers to bring down the gain. The AGC is IF derived from the output of the second CA3028; some further tinkering with the circuit values of the original circuit was necessary to get reasonable AGC response.

Even with tinkering, I'm not really enthusiastic about this IF/AGC circuit. Real DXing can take place with the AGC off, as it doesn't kick in until a -95 dBm signal is applied at the receiver input. Most DXing of domestic channels is fine with the AGC on, in either fast or slow decay positions, depending on conditions. But the the IF/AGC subsystem does start to overload when an input signal of -75 dBm or greater is applied to the receiver input. This has meant that switchable attenuation is required to listen to stronger domestics or when using a good antenna such as a Beverage. Also, I would like to have an S-meter that indicates at low signal levels so that I can make antenna comparisons on DX signals. My present S-meter indicates for receiver input levels of -95 dBm to -62 dBm, due to the limited AGC action of this set-up.

The IF filters and their associated circuitry should be considered part of the IF amplifier subsystem also, as they contribute to the gain as well as the selectivity of the IF strip. The circuit between the mixer output and the input to the IF/AGC strip contributes about 25 dB to the overall IF gain, although we'll consider the post-mixer amplifier as part of the mixer circuit, and just discuss the IF filters and surrounding circuitry for now. My first IF filter is a MuRata CFS-455J which might be considered unusual when Collins mechanical filters are available, but the MuRata has a respectable stopband of over 70 dB (85 dB is available with better mechanical filters) and is considerably cheaper. I feel that this ceramic ladder filter deals better with transient splatter and noise peaks than the mechanical filters that I have tried. It doesn't reject the peaks any better; it simply makes them sound a little less offensive. It also handles weak signals without preamplification better than a mechanical filter does. The one disadvantage of the MuRata is its minimum -6 dB passband of 3 kHz. In fact, this passband is usually more than 4 kHz which is rather wide for tight split channel DXing. So a 2.9 kHz Collins mechanical filter follows the MuRata interspersed with a grounded gate amplifier which has a reasonably high signal handling capability. This amplifier is necessary in order to bring very weak signals up to a level which the Collins filter can handle. Almost all DXing is done using the Collins filter, but another MuRata filter can be used instead of the Collins (via diode switching from the front panel) if a wider passband is desired.

Don Moman tested the 50:2000 L-match, the first IF filter and its following amplifier for me, and found that the minimum discernible signal at its input was -134 dBm with a 4 kHz passband, which is pretty respectable, and meant that I would need virtually no overall amplification between the antenna input of the set and the input to the first IF filter. If you look at the accumulated gains and losses through the front end of the receiver, you will see that the receiver is built this way, in fact.

The mixer of a receiver is where most signal-handling and overload problems take place. This receiver uses a Mini-Circuits TAK-3H diode ring double balanced diode mixer module which has an output intercept of +28 dBm. This provides a higher level of signal handling than is available in any commercially sold receiver, though it is still not the best mixer available. Such a module doesn't add to the complexity of a receiver; in fact, the TAK-3H is the only component in the mixer block of the diagram. For best results however, the module should see a broadband 50 ohm termination at each of its ports, which explains the -3 dB 50 ohm attenuator at the RF and local oscillator inputs to the the TAK-3H. The "diplexer" which follows the mixer is a simple RLC circuit which also provides a 50 ohm termination at all frequencies. Details appear in Solid State Design for the Radio Amateur and other texts.

This kind of mixer should be immediately followed by a low noise RF amplifier with a well-defined input impedance, so that the receiver noise figure will not be further degraded after the lossy mixer. The one used here is a "noiseless feedback" amplifier, a grounded base circuit based on a broadband VHF design described by Joe Reisert on page 101 of the November 1984 Ham Radio magazine. This amplifier is supposed to have a noise figure of 2 dB or less using the specified transistor, and the circuit is followed by a 3 dB pad to help keep its signal handling capability higher than that of the preceding mixer. Unfortunately, my post-mixer NE41632B has started to get noisy, though it is only a problem when trying to log one of the RPH Australians using an unamplified loop antenna at dawn. Any suggestions as to where I can get this transistor or one which is as good?

There are two drawbacks to a good diode ring double balanced mixer. One is price; mine cost Can$50, though US buyers could probably find it for less. The other is that this mixer requires +17 dBm worth of local oscillator power to drive it adequately, which with the 3 dB pad means my L.O. must deliver +20 dBm, on the order of 100 milliwatts. A pair of class A amplifiers with 35 dB gain using 2N5179 and 2N5109 transistors brought my local oscillator up to the required power throughout most of the MW range. Output drops off a bit at the bottom of the band due to a weaker signal from the oscillator circuit around 1000 kHz.

The oscillator itself is a Clapp type using a 3SK85 MOSFET, a 120 uH coil wound on a T106-6 toroid, and a variable capacitor in the 400 pF range, plus various polystyrene fixed capacitors. Very fine tuning, on the order of fractions of a Hertz is provided by a pair of varactors and a 10 turn potentiometer voltage divider. Another example of over-design perhaps, but it could be handy when some form of exalted carrier detection is added to the receiver. This local oscillator yields a 516 to 1650 kHz MW coverage in the receiver, and the geared down variable capacitor allows me to tune within a few Hertz of the carrier with little backlash. I do get some drift problems with this oscillator within a few minutes of switching it on, 100 Hertz or so, but it soon settles down. I would prefer no drift at all, but haven't mastered it yet!

JFET buffers transfer the oscillator signal to its power amplifier and also to the PCIM177 LCD readout module. This useful module is no longer available in the USA, but might still be obtained from Cirkit Holdings in Britain. Current consumption is a couple of milliamps and the readout does not generate RF noise when enclosed in its own small metal case with a JFET buffer.

As this receiver uses a 455 kHz IF, a fair amount of preselection is needed to provide adequate image rejection at MW frequencies. The tuneable RF filter used is a four inductor, three gang capacitor type known as a Cohn filter. Its design parameters can be found in Ferromagnetic Core Design and Application Handbook by M.F. DeMaw, Prentice Hall 1981. As my variable capacitor has five gangs, I tried to make this a one handed tuner by ganging the RF filter and local oscillator sections. It would only work if I placed small variable capacitors across each of the gangs of the RF filter variable capacitors. So it's not quite a one-handed tuner; more like one-handed plus a quick touch up for maximum signal on the three front panel trimmers. I've learned to live with it.

Constructing this filter and the local oscillator was the biggest challenge in building this receiver, as each filter section and the oscillator needed to be shielded. I ended up building a copper clad PC board box around each gang of the variable capacitor. The shielding seems to be successful, but as I'm no metalworker, I do have problems with trimmer capacitor shafts binding somewhat as they go through several sections of PC board.

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Following the RF filter is the same kind of low noise RF amplifier used in the post-mixer section of the receiver. It is there to compensate for the filter loss and to keep the overall noise figure of the receiver low.

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As I've said, this receiver has been in use for 3½ years now, in B.C., Washington and Alberta using loops, Beverages and random wires. It's travelled on land, sea and air and been used in temperatures of 10^{o} to 90^{o}F. with varying levels of humidity. So far, the only component problems have been that noisy transistor, a bum switch, and a touchy headphone jack. The best DX heard was 5CL-729, 50 kw at 8000 miles, while the unamplified loop was pointed to it and 50 kw CKLG-730 60 miles away. Conditions helped, I'm sure, but I like to think the receiver did its part.

Don Moman and I ran this radio through sensitivity and intermodulation tests in early 1987. The minimum discernible signal was found to be -133 dBm, roughly a sensitivity of 0.2 uV using a 10 dB signal plus noise to noise ratio. Standard two tone (separation of 50 kHz) dynamic range tests gave a value of just over 100 dB which is pretty reasonable, but not as good as expected, as it is only equivalent to what the R-5000 or IC R-71 are capable of. However, when the two tone tests were repeated with signals separated by only 3.5 kHz, my radio continued to show IMD performance of around 96 dB, while the R-5000 and R-71 were poorer than 70 dB. As the 3.5 kHz separation more closely mimics toughest DXing conditions, this result was rather important to me.

This receiver is <u>not</u> finished:

1) Its sections are presently housed in old stereo amplifier case, which desperately needs a proper front panel. I'd like something that works this well to look pretty as well.

2) I've got to do something about those binding trimmer capacitors. I'd like to try varactors to avoid the mechanical problems associated with the trimmers, but suspect they will introduce distortion on strong signals.

3) I'd like to improve the IF amplifier, especially its AGC section, so that a wider range of signal strengths can be monitored without distortion. As I often experiment with antennas, I'd like an S-meter which gives me a wide range of accurate signal strength readings.

4) Concomitant with above, I'd like to add a very narrow IF filter so that I could monitor carrier strengths alone when I'm experimenting with antennas or circuitry. No S-meter can give accurate indications when a weak signal is awash in sideband splatter.

5) Sideband splatter is the main enemy of split channel DX. There's lots of work to be done using upper/lower sideband exalted carrier detection, synchronous detection, and USB/LSB diversity reception derived from either of these methods.

6) Although I've rarely needed an IF notch filter, I'd like to try one out, and even have a section in the receiver put aside for it.

7) I'd like to have the time to do all of the above. Send your winning lottery tickets to the address on the masthead!

BLOCK DIAGRAM NICK'S RECEIVER