A Homebrew High Performance HF Transceiver — the HBR-2000

VE7CA shows us that it's still possible to roll your own full feature HF transceiver — and get competitive performance!

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Have you ever dreamed of building an Amateur Radio transceiver? Have you thought how good it would feel to say "The rig here is homebrew." I did, but I am not dreaming anymore. I am the proud owner of a homebrew, high performance, 100 W HF transceiver. I have named it the HBR-2000.

I am writing this article to encourage you to stop dreaming and pick up your soldering iron. In my early years as a ham radio operator, I built several transmitter kits and later, as I gained experience, I began building solid state direct conversion receivers and low power (QRP) single band transmitters. Six years ago I said to myself: "I am not going to dream any longer. I am going to build my dream transceiver." Here is a description of how it all came together. Note that this is not a construction article, but rather a description of the process.

I began by first making a list of the features and specifications I wanted in a high performance transceiver. Then I began drawing various circuit blocks that, combined together, would meet the requirements of my wish list of features. The HBR-2000 block diagram is shown in Figure 1.

The secret to being able to successfully build a major project such as this is to divide it into many small modules as indicated in the block diagram. Each module represents a part of the whole with each being built and tested before starting on the next. To choose the actual circuits that were to be built into each module I searched past issues of *QST*, *QEX*, *The ARRL Handbook for Radio Communication*[1] and publications dedicated to homebrewing such as *Experimental Methods in RF Design*[2] by W7ZOI, KK7B and W7PUA, recently published by ARRL. If you do not own a copy of these, I highly recommend that you order copies today. In my opinion, these are the two most valuable books you can have in your ham shack if you want to design and build a transceiver.

[1]Notes appear on page 38.

I cannot overemphasize the importance of learning by reading, building a circuit and then taking measurements. After you build a particular circuit and measure the voltage at different points, you begin to understand how that particular circuit works. Ward Silver, NØAX, has been running an excellent series in *QST* called "Hands-On Radio." I found this month-by-month electronic tutorial especially helpful. I followed along each month as Ward explained how different radio circuits and components work and how to calculate, adjust and measure parameters of various circuits. If you are not an electrical engineer, or your electronics knowledge is a little rusty, go back and read these issues to help increase your knowledge of modern day electronic components and theory.

When I found an article containing a circuit that fulfilled the design features I had previously chosen, I checked my parts bins and then began procuring the parts I didn't have on hand. In some cases, if an etched PC board was available, I ordered it. I did not go on to the next module until I had finished the first module, including testing it to make sure it worked as expected. After I built the first module I followed the same process to decide on the circuit and build the second. I would then connect the two modules together and check to make sure that, when combined, they performed as expected. It is really that simple — one step at a time. Anyone who has had some building experience can build a receiver and transmitter using this procedure.

For a receiver, I recommend beginning with the audio output stage. In my case, I had on hand an extra printed circuit (PC) board for the "R1 High Performance Direct Conversion Receiver" by Rick Campbell, KK6B, featured in the August 1993 issue of *QST*. Rick took particular care to design a low distortion audio stage preceded by a field effect transistor (FET) mute switch and a double balanced mixer that can be used as the product detector. After mounting all the components on the PC board, I wired a speaker to the audio output pad and +12 V to the power input pad to test if I had audio output. I did this by injecting an audio signal from a code practice oscillator into the input stage of the pre-amp and confirmed that, indeed, the audio amplifier was working. Using a 40 meter variable frequency oscillator (VFO) from a low power rig that I had previously built I connected the VFO output to the mixer local oscillator (LO) port. I made sure that I didn't over-power the mixer as the LO port is rated at no more than +7 dBm. After attaching an antenna to the antenna port, I was able to hear CW signals coming out of the speaker. Hurrah, it worked!

After building the audio amplifier and product detector module, I built the beat frequency oscillator (BFO) circuit. From there, I built the intermediate frequency and automatic gain control (IF/AGC) module, then the VFO and the heterodyne LO system, then the receiver mixer and on and on until I reached the antenna. At that point I had a functioning receiver. It was a thrilling day when I hooked

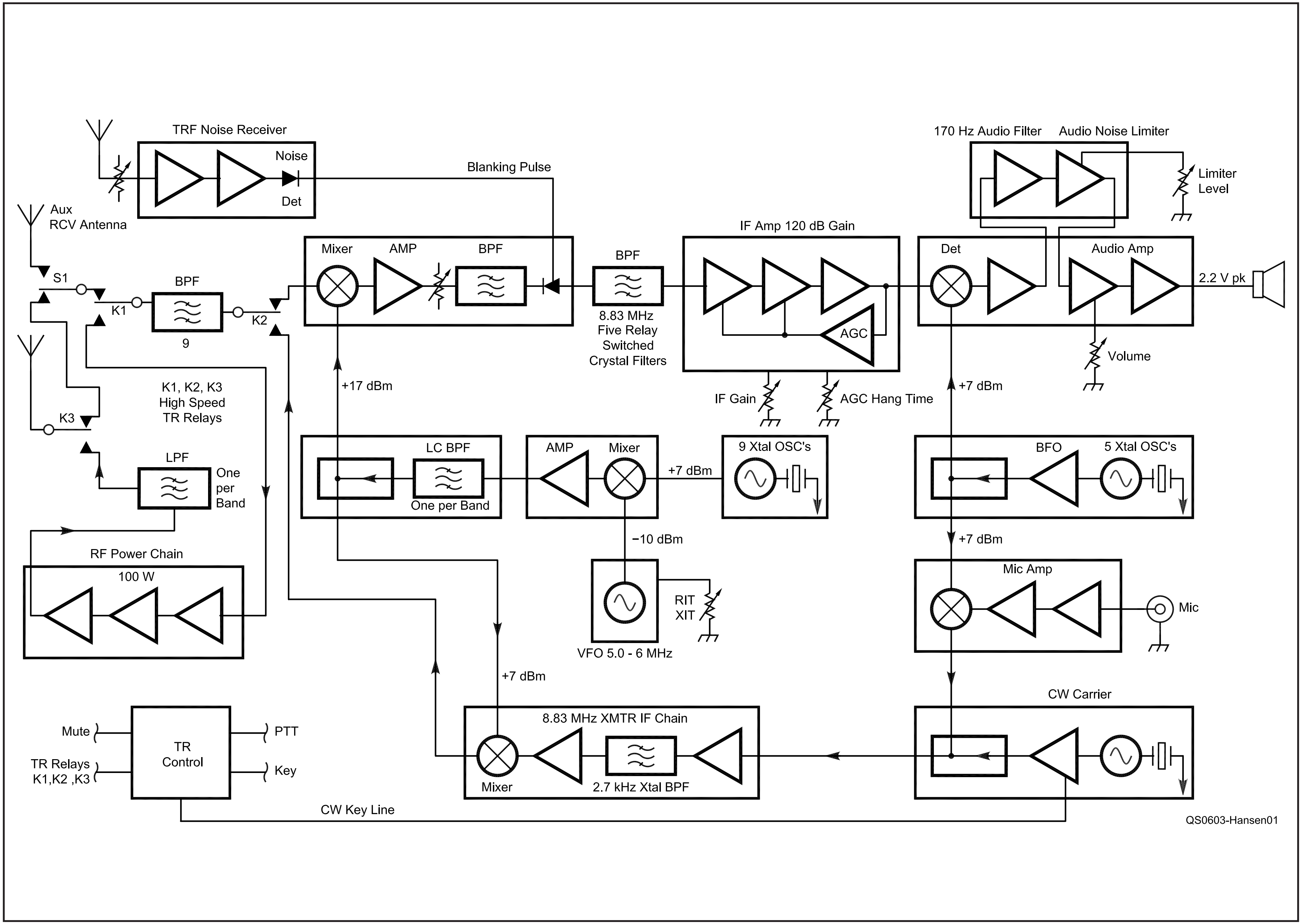

Figure 1 — Block diagram of the HBR-2000.

up an antenna to the receiver and could tune across the amateur radio bands listening to signals emanating from the speaker.

One of the things you will learn as you begin building your own equipment is that RF radiates. RF travels along power, speaker and control leads. All of these leads act like little antennas. This fact, coupled with the fact that the receivers we use today are very sensitive, can make for some challenges. After you build a particular module, you don't want RF from outside sources to get into the modules you build and you don't want RF signals produced inside the modules to travel to other parts of the receiver, other than through shielded coaxial lines. The reason that you don't want RF floating around the receiver is that stray RF can produce unwanted birdies in the receiver, adversely affect the AGC system or cause other subtle forms of mischief. To prevent this from happening I enclosed each module in a separate RF tight box and used coax for all the RF lines with BNC or phono connectors on each end. All dc and control lines are connected via feed through insulators.

My modules are enclosed in boxes made from unetched copper clad material. For the covers I cut sheet brass half an inch wider and longer than the size of the PC box. I then laid the box on top of the brass and centered the box so that there is about ¼ inch overlap around the perimeter of the box and drew a line around the box with a felt pen. I then cut the corners out with tin snips and bent the edges of the brass cover over in a vise. By drilling small holes around the perimeter of the box, inserting wires through the holes, soldering the wires to the inside of the box and to the overlapping edges you produce an RF tight enclosure. See Figure 2 for an example of this technique.

Figure 2 — Sample of a box made with PC board with a sheet brass cover overlapping all four sides. Note the BNC connectors and feed through insulator.

Types of Construction

When you begin building your own radio equipment you will find that there are many different methods of mounting electronic components. There are methods employing single and double sided etched PC boards, perforated boards, Manhattan breadboarding techniques and others. My audio board and IF board are etched PC boards purchased from FAR Circuits. But the construction method I learned to appreciate the most is a method known as "ugly construction." This method was originally in the August 1981 issue of *QST* in which Wes Hayward, W7ZOI, described how he built the legendary "Ugly Weekender."

You can find a detailed description of this method in *Experimental Methods in RF Design*. An unetched copper clad board is used for a base (or ground plane). Begin building by starting at the circuit input and work towards the circuit output, soldering components in place as you go along. The ground side of components such as resistors, capacitor or ground leads of an IC are soldered directly to the ground plane. The wires coming from the top side of the component are used to connect to other components. When I have an IC in a circuit, I turn it upside down on the PC board, mark pin 1 with a black dot using a felt tip marker pen and then bend the ground lead over and solder it to the ground plane. That holds it in place while I make the other connections. As I solder components in place, I draw a picture diagram of each component and the connecting wires. I use a red pencil to draw dc power lines, and a different color to draw control lines like TR switching lines, etc. This is a very important step, and it is particularly helpful when troubleshooting a circuit that isn't working.

The beauty of the ugly construction method is you can see all the wiring. You do not have to turn it over to see where the connection leads are as you do with etched PC boards as the traces are on the bottom of the board and the components are on the top. (This is not the case with surface mountings techniques but that is another story.) Ugly construction is particularly appreciated after you have built a board and mounted it inside one of the boxes you made. You don't have to take the board out to make changes to a circuit because everything is on the top of board. Also you can build a circuit using the ugly construction method much more quickly than laying out a PC board design, etching it, drilling holes and then mounting the components.

Once you become proficient in building "ugly" style, you won't go back to etched circuit boards unless you plan to make many boards of the same circuit.

Hooking it all Together

Each module is designed for an input and output impedance of 50 Ω except for the audio output that, in my case, is 8 Ω for speaker connection. Thus I am able to employ 50 Ω coax cable with BNC connectors to connect the RF paths between the different modules. An added benefit of this construction method is that if I decide in the future to try a different

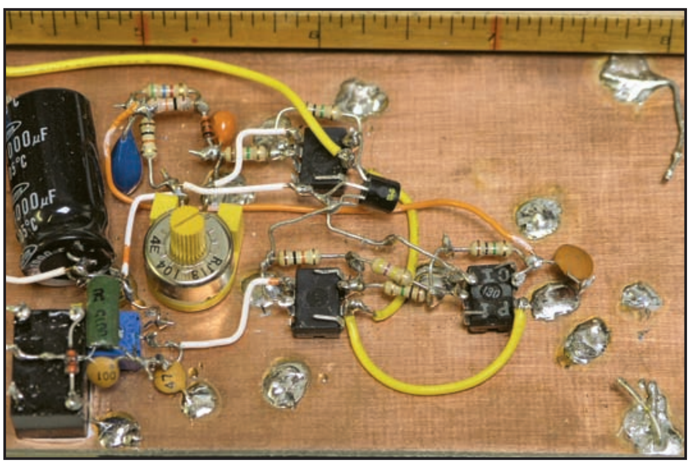
Figure 3 — Sample of "ugly construction" method.

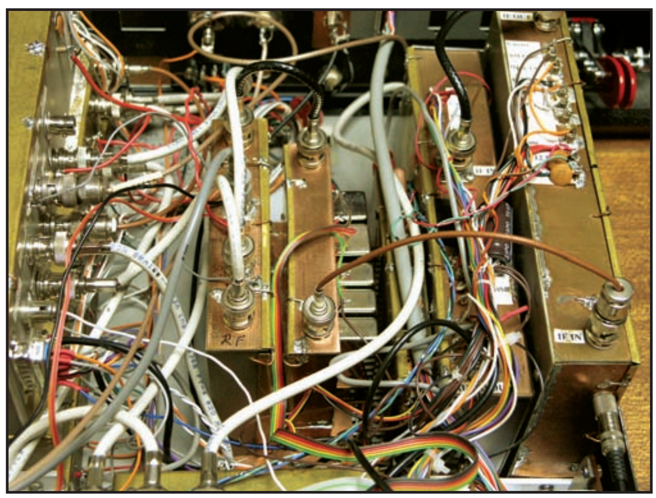
Figure 4 — The inside of the HBR200. All the boxes are connected together with 50 Ω coax and BNC connectors for the RF runs. All dc power and control leads, in and out of the boxes, are through feed through insulators.

Figure 5 — The VE7CA work shop shows some of the home built and surplus test equipment used in the construction of the HBR-2000.

circuit for a particular module, I build the new circuit and mount it in a new box, disconnect the old design and insert the new one in its place. In fact I have already done this very thing on several occasions. I tried three different front end receiver mixer designs before settling on the final mixer design. Since I had more than one mixer circuit, all in separate boxes, I was able to make accurate, comparative measurements by substituting one box for another, thus allowing me to make an educated decision as to the mixer design I was going to keep.

Measurements

Making meaningful and accurate measurements is a major part of producing a successful project. You must make measurements as you progress in the building process or you have no way of knowing whether a module is performing according to your design specifications. Let's look at it this way. If you are building a receiver and you want it to be competitive in the HF bands, it should be able to detect a very weak signal, say –130 dBm (0.07 µV). In order to make this weak signal audible, it has to be amplified by the receiver to a certain level. I decided from experience that, 2.5 V_{PP} into an 8 Ω speaker, at maximum volume, was sufficient.

If I inject an S3 signal at 14.025 MHz into my receiver antenna input, and turn the audio volume control to maximum setting, my scope reads 2.5 V_{PP} across the speaker leads and the tone I am listening to is loud. It just didn't happen that way. Each module has either gain or loss. RF band-pass filters, IF filters and mixers are generally lossy. So, loss in one stage has to be compensated for by gain in other stages, typically the IF stage and the audio stage. Once the distribution of gain is decided upon by the designer, the gain of the different stages must be measured to ensure that they are performing as designed. This requires the use of test instruments.

As an example, if one wants a double balanced mixer to perform according to the manufacturer's specifications, the LO port has to be driven with the correct level of RF power and at the right impedance. One of the specifications I had chosen for the HBR-2000 was that it should have a very strong front end. To accomplish this I chose a mixer that requires that the LO port be fed with +17 dBm at 50 Ω. Having the test equipment to measure these parameters gave me the assurance that I was going to obtain the results I was looking for.

Test Equipment

When I decided to build my dream transceiver I began the process of either building or purchasing surplus test instruments. I built crystal controlled, very low power oscillators and attenuators to measure receiver sensitivity. I also built high power oscillators and a combiner to measure receiver blocking and dynamic range. In addition I purchased a used oscilloscope and later was able to find a used signal generator. I also built a spectrum analyzer, which turned out to be one of the most useful instruments, since my HBR-2000 has 19 band-pass filters and 22 low-pass filters. You will find instructions how to build this instrument in the August and September 1998 issues of *QST* in an article by Wes Hayward, W7ZOI, and Terry White, K7TAU. Later I built the RF power meter featured in June 2001 *QST*, authored by Wes Hayward and Bob Larkin, W7PUA. These instruments allowed me to adjust and measure the performance of each module that I built. Of course all measurements are carefully entered into a journal for future reference in case of a problem.

Be resourceful when collecting test equipment. Check your local ham club. You

Figure 6 — The 100 W amplifier board.

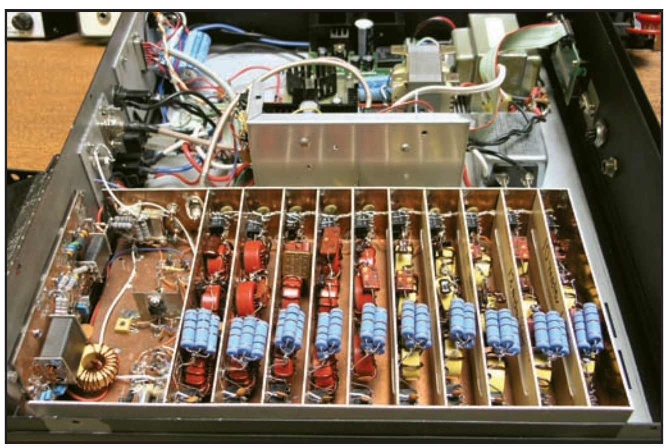

Figure 7 — The 100 W amplifier, 10 low pass filters and the power supplies are located in separate subenclosures.

Figure 8 — VE7CA's partly homebrew Amateur Radio station.

Table 1
HBR-2000 Test Measurements

Image rejection all bands:	>135 dBm.		
Spacing:	*20 kHz*	*5 kHz*	*2 kHz*
Two-tone blocking dynamic range:	>126.0 dB	124.0 dB	122.0 dB
Third-order intermodulation dynamic range:	103.5 dB	102.5 dB	93.0 dB
Third-order intercept:	25.5 dBm	24.0 dBm	14.5 dBm
Receive to transmit time:	8 ms (incl 2 ms click filter).		
CW, full QSK transmit to receive time:	8 ms (30 WPM = 20 ms dot).		

may find that a member will even donate a piece of test equipment that is surplus or not being used when they find out you are building your own radio equipment. Other sources are ham radio flea markets, swap and shop nets or auction sites. You will be surprised how little you have to spend to assemble a good selection of test equipment.

Other Circuits

Here are some of the sources used for deciding on the circuits for the other modules in the HBR-2000 design. The VFO design is from *QST* June 1991, "Build a Universal VFO" by Doug DeMaw, W1FB. The first mixer, post-mixer amplifier and crystal heterodyne oscillator design was taken from "A Progressive Communication Receiver" design by Wes Hayward and John Lawson, K5IRK, which appeared in November 1981 *QST* and was also featured in *The ARRL Handbook* for many years. This is a classic radio article with many good circuit ideas. The IF subsystem design is from B. Carver, K6OLG, "A High-Performance AGC/IF Subsystem," May 1996 *QST*, pp 39-44. The receiver input RF band-pass filter and diplexer designs along with the noise blanker and 100 W amplifier circuits were taken from the John Stephensen, KD6OZH, three part series beginning in the May/June 2000 issue of *QEX* titled "The ATR-2000: A Homemade, High-Performance HF Transceiver." The BFO and power supply circuits were lifted right out of *The ARRL Handbook*. The transmitter portion of the transceiver consists of combinations of various circuits found in *Experimental Methods in RF Design*.

It is no secret; all the circuits you need to build a high performance transceiver are available in the various ARRL publications mentioned in this article.

Receiver Specifications

There may be some reading this article who question whether an amateur can build a competitive grade contest class transceiver from scratch. For the skeptics, the actual measured performance [confirmed in the ARRL Lab — *Ed*.] of the HBR-2000 is shown in Table 1.

Receiver sensitivity measurements on all bands are within ±0.5 dB of –130 dBm. All measurements were made with an IF filter bandwidth of 400 Hz. Test oscillators are two separately boxed crystal oscillators, low-pass filtered and designed for a 50 Ω output impedance. MDS measurements were made with an HP-8640B signal generator and a true reading RMS voltmeter across the speaker output.

The receiver measurements were made following ARRL procedures as outlined in the ARRL "Lab Test Procedures Manual." If you are an ARRL member, you can find a copy of this document at **www.arrl.org/members-only/prodrev/testproc.pdf**. Making accurate receiver measurements is not a trivial matter and should be approached with the understanding of the limitation of the test equipment being used and thorough knowledge of the subject.

The question I am often asked is, "Is it possible for a ham to build a transceiver that is comparable to high performance commercially available Amateur Radio transceivers?" I am here to tell you it is possible. Recently I had the opportunity to compare my HBR-2000 to a high end commercial transceiver that is used by many major contest station operators. I found that on many occasions during the March 2005 ARRL CW DX Contest that while using the HBR-2000, I was able to hear and work very weak DX stations that were sandwiched between two very closely spaced, strong local stations calling CQ (50 to 60 dB over S9). On many occasions the same weak DX station was not discernible in the commercial transceiver. Why? Because I employed a single conversion receiver design with a very good 250 Hz IF filter following the first mixer. The commercial transceiver has a 6 kHz wide roofing filter in the first IF so that the two very loud CW signals were within the same filter bandwidth as the weak signal and together they produce intermodulation distortion products and close-in synthesizer noise that covers up the weak signal. You have to hear it to believe it.

You may notice that I have not made any attempt to miniaturize the HBR-2000. Modern transceivers tend to use closely spaced small knobs except for perhaps the VFO. While you are adjusting one knob, it is easy to touch and move another knob and not know it. Also, many functions employ concentric knobs with very small labels that I find hard to read in low light. Small is great for portable rigs, but for a home station transceiver you should be able to adjust one knob and not have to worry about touching another. With large knobs and large labeling, I am able to operate my transceiver without the need for my reading glasses. By building my own equipment I am the one who decided the receiver front panel layout, what size knobs I was going to use and where they would be located. That is a real bonus!

Building something with my own hands provided me with a lot of enjoyment. Therefore, I was not in a hurry to finish building the HBR-2000. Why hurry to build something? When it is finished you have to find another project to build to satisfy the enjoyment you feel while building. It took me five years, while also working full time, to completely finish the HBR-2000. I had the receiver working after two years and the transmitter portion took another two years followed by one more year refining the QSK circuit, adding a noise blanker and a 100 W power amplifier. You may say that is a long time but I feel it is worth it. I am now enjoying the fruits of my labor.

Notes

[1]Available from your ARRL dealer or the ARRL Bookstore, hardcover ARRL order no. 9493, softcover ARRL order no. 9485, Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop/**; **pubsales@arrl.org**.

[2]Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 8799, Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop/**; **pubsales@arrl.org**.

Markus Hansen has been an Amateur Radio operator since 1959. He has no formal electronics training but likes experimenting and writing articles about his experiences. He has had articles published by the ARRL in QST, QEX *and the* Antenna Compendium *series. You will find Markus in many of the HF CW contests as well as on 6 meters. He is always on the outlook for the last few countries that he needs for the DXCC Honor Roll. His Web site,* **www.shelbrook.com/~ve7ca**, *describes additional technical details about the HBR-2000 as well as other homebrew projects and antennas that he has built. You can reach Markus at 674 St Ives Cres, North Vancouver, BC V7N 2X3, Canada, or at* **ve7ca@rac.ca**.