Bob Evans, K5WA

A Texas-Sized Band Decoder

My longtime friend Bob Burns, W5SJS, got tired of my whining about not being able to find any reasonably priced land for a contest station in the country. So, he offered me access to his existing station near Brenham, Texas — an hour north of Houston. This was a sweet arrangement for a wannabe contender like me to stumble into. I jumped at the chance to build a competitive contest station at "The Ranch." Bob had two tall towers with rotatable Yagis for 40 through 10 meters, which gave him and Joe, W5ASP, a place to work DX and to dabble in contests.

Today there are three Yagis for each band, 20 through 10. There are four antennas for 40, including a 4 element Yagi at 160 feet. On 80, we have an elevated radial four-square (per ON4UN) and a 2 element delta beam. On 160 meters, we have a 2 element phased array and multiple 1000 foot Beverages. A lot of time went into getting the new antennas positioned and installed, but I had not spent much time taming the resulting pile of coaxes and StackMatch control boxes that had popped up in the shack. When the time came to configure the station for either an SO2R operation or a multi-single operation, we had to track down the correct cables and hook them up for that particular weekend's situation. We also managed to break plenty of coax adapters as we pulled and pushed on the cables, getting them ready for contests.

Even though we currently have only three rotators (because most of the antennas are fixed), swapping rotator control boxes between operating positions was a time-consuming event as well. I knew there had to be a better design for this mess, and a project was born. My goals were:

1. Eliminate all rotator and antenna control boxes from the operating position and replace them with a single touch screen per operating position. The screen should present only the antennas and rotators available, given the particular band/rig selection status of the station's three Elecraft K3s (two in the SO2R position and one in the multi-single position).

2. Build a rotator control with *preset* directions, brake delay and manual fine adjustment, with digital and analog readouts. Include provisions to link rotators to a single readout for future stacking needs.

3. Never again have to swap coax around manually to configure the station for a particular contest or entry class (ie, SO or MS; conceptually this also could apply to a multioperator implementation, if this system were expanded). The control system should "sense" which rigs are powered up and configure itself to fit that entry class without any user intervention.

4. End up with a *single* RS-232 connection to the control system, so all antennas could be eventually controlled over an Internet remote link, which is the next phase of this project.

5. Design the control system to protect rotators, RF path switches and rigs by building in timers and fail-safes.

6. Incorporate Internet connectivity and full uninterruptible power supply (UPS) support for future remote operation.

7. Install adequate lightning protection on all antennas and rotator control cables.

8. Do it all as cheaply as possible.

PLC — the System's Brain

I'm in the oil and gas refinery automation business and am familiar with various industrial controls, so I thought I could use a programmable logic controller (PLC) as the heart of this project. Please understand, I'm "the sales guy" and *not* the technical guy, so jumping into this was going to mean a steep learning curve for me.

After doing some research, I found a company called AutomationDirect (**www.automationdirect.com**) that caters to small to medium-sized companies and individuals doing automation projects. They had a new line of PLCs called the CLICK series, and it looked like a great fit for my project. It is a modular design that lets you start as small as a few inputs and outputs (I/O), adding modules as needed to increase your I/O count up to 142. The basic CPU with a couple of analog inputs, four dc inputs and four dc outputs cost just \$129. If you don't need the analog part, it's only \$69. Additional I/O modules are in the \$35 range. That fit my definition of cheap.

The programming software is free, and the accompanying touch screen C-more Micro-Graphic 6 inch panels are not too bad at \$299 each. The C-more Micro-Graphic panel programming software is free. One potential downside to this particular line of PLC is that it only uses "ladder logic" programming language. More expensive PLCs can employ "function block" programming (and several other methods), and these are easier to use for complicated control schemes. I was convinced, however, that I was up for the challenge of building this project using ladder logic.

Planning

In laying out my project plans, I wanted to keep my existing hardware: Tower-mounted StackMatch units, station-mounted SixPak, ICE 419 band-pass filters, Hy-Gain rotators, Top Ten Devices A/B switches, Comtek 80 meter four-square controller and Comtek 160 meter phased array controller in combination with the three Elecraft K3s. I needed to understand the switching logic of each of these devices as well as the control voltage required, so I could build the system correctly.

The CLICK PLC I/O modules can either source or sink various voltages, depending on the module you choose. I needed to have both 12 and 24 V dc for most uses, and the CLICK I/O modules fit very well, but I also used relays for the 24 V ac rotator logic. I based my plan on an estimated total I/O count by voltage in a spreadsheet to make sure I had covered everything. I then added 20 percent to the overall count to cover mistakes, additions and creative moments of inspiration that might hit me. That was a good plan, because the end result was to almost max out (~140 I/O points) the eight I/O modules allowed in a fully loaded CLICK system. Fortunately, if I ever need to add much more I/O, you can build up a second CLICK PLC and let the two pass information back and forth to act as a single system.

This system can be thought of as a band decoder on steroids, because I built it to be driven by the BCD band information found on the K3's AUX port. I use 12 (5 V dc) inputs on the CLICK PLC to tell me whether a particular K3 is turned on as well as which band it is on. That information selects the correct screen that needs to be presented to show particular antennas and rotators available for a band choice.

There are two design philosophies on screen design. You can develop a small number of screens having discreet dynamic segments that follow band changes or you can develop a larger number of screens with hardwired segments and just swap screens as the band information changes. I chose the hardwired path, since it seemed more straightforward to me. If this project were much larger, I would have gone with dynamic segments. There

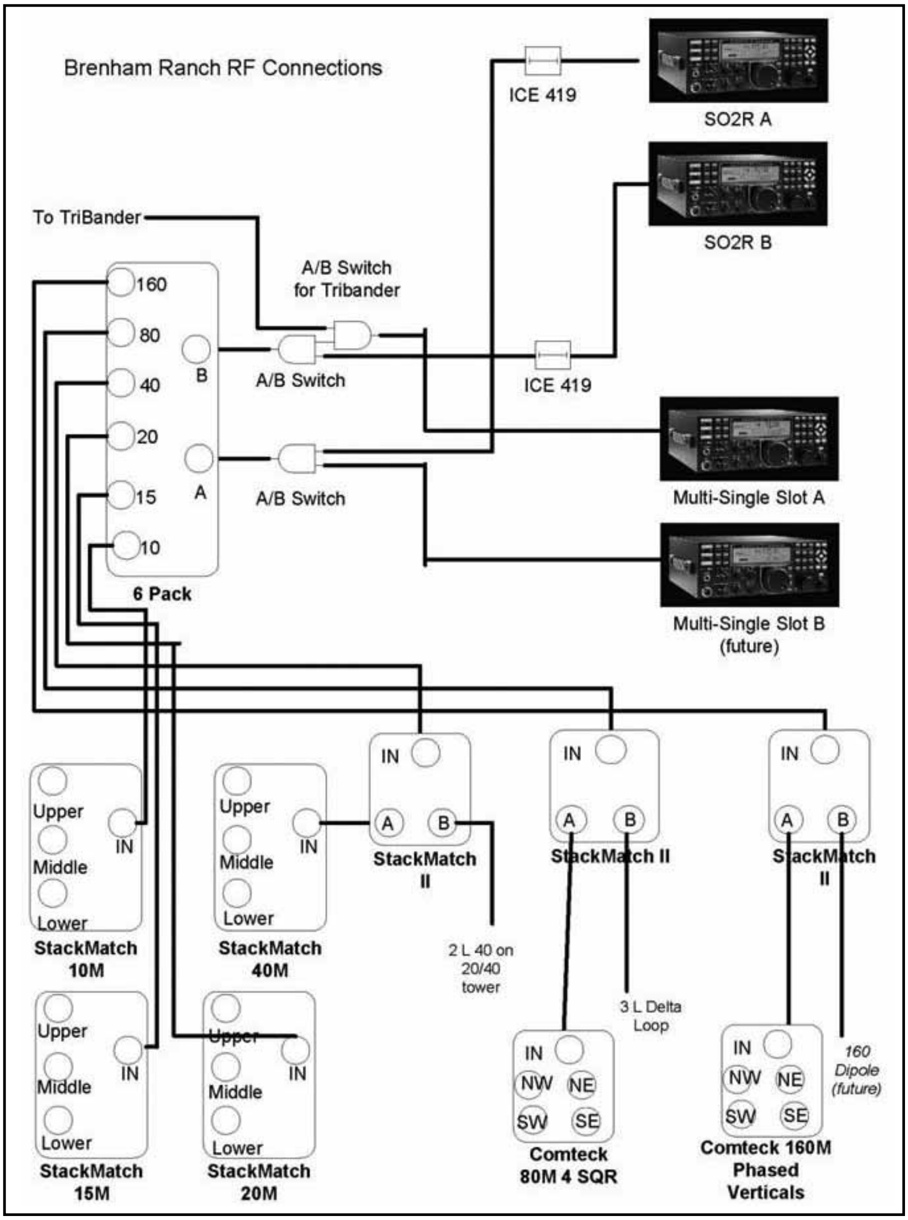

Figure 1 – Basic RF Path Layout

are about 100 screens in four categories to cover my possible operations. The categories are (1) Rig A of the SO2R station is the only one powered, (2) Rig A and Rig B are both powered, (3) the MS operating position is powered in addition to SO2R Rig A and, and (4) the MS position alone is powered. If there is only one rig powered at the SO2R position, the screen displays options for a single band. When both Rig A and Rig B are powered and no MS position rig is on, the SO2R screen shows *both* available antenna options on one screen.

Rotator Control

Once I got around to understanding what is really going on in a Hy-Gain HAM-IV and Tailtwister rotator box, I thought I would have no problem reverse engineering that "simple" circuit. I quickly figured out, however, I needed my good friend Kim Carr, K5TU, to give me a refresher course on Ohm's Law and voltage drop. With Kim's extreme patience and circuit suggestions, I finally came up with a circuit that accomplished what was needed to replace the Hy-Gain control boxes.

As I started wiring these three rotator circuits (one each for 10/15, 20 and 40) into the control system, I learned a basic lesson about ground loops. My analog input circuit uses the 500 Ω pots in the rotators. The wiper of that pot is grounded and comes back to the control system on the same wire as the ac neutral for the rotator motors. The pot voltage jumped around like crazy whenever the rotator motor or brake was activated. You electrical engineers out there are rolling on the floor laughing right now, but some of us appliance operators need to think through the ac/dc interface to digest this idea as we try to reverse engineer the old reliable rotator control box. I have a new appreciation for the guys who first came up with the elegantly simple design that has served Hy-Gain well for all these years.

Once I finally understood the problem, AutomationDirect again had an answer with its signal isolation devices. These devices isolate my dc indicator pots from the ac motor circuits and also allow a voltage-transformation option. I was able to use the 10 V dc to 5 V dc conversion mapping in the signal isolators and have 10 V dc full scale at the rotator pot translated to the 5 V dc input required on the analog input of the CLICK PLC. The isolator also gives me a 20 percent adjustment in span, so I can correct (to some degree) for non-linearity in the pot circuit. I have a separate "zero" calibration pot in each rotator circuit, which is not affected by the span adjustment.

The next hurdle was writing the ladder logic steps to convert the PLC's analog input into a usable touch screen indicator. A complicating factor was that all of the C-more Micro-Graphic panels' meter scale templates were north centered as opposed to south centered. I needed to build a math model that broke the 360° dial into two 180° halves and swap between them when the indicator crossed over 0° (ie, due north). It took a lot of head scratching for me to figure this out, but it works pretty well now.

The more expensive PLC might have saved me time by offering function blocks to do the same thing I ended up building from scratch, although that was very satisfying. Writing the rotator brake delay, motor control and preset direction logic was pretty straightforward, and I finally was able to make one rotator work as it should.

Once each rotator was functioning correctly, I had to work on the logic of channeling the three (and soon to be more) rotators to Rig A and Rig B of the SO2R position. I decided to pass all eight rotator control lines through a relay logic channel, and AutomationDirect again came to the rescue by supplying very nice 4PDT 24V dc relays and holders at cheap prices.

The CLICK PLC runs on 24 V dc from its own power supply so 24 V dc was readily available. I used the PLC to switch these relays correctly, which gave me isolated paths between rotator channels A or B and each rotator. Each rig of the SO2R position has one rotator per band (see Figure 2). Rig A is the upper half of the screen, and Rig B is the lower half. These positions could be swapped, if Rig A moved to Rig B's band and vice versa, so the rotator control function can be thought to "move" between rigs as required.

I built a digital indicator (shown with 000 placeholders above) as well as an analog bar (space below 000 and above SWNES) to show the antenna direction. The digital readout is very sensitive and bounces during rotation due to rotator pot inconsistencies and some remaining ground loop issues. When you use the standard control boxes, these bounces are not overly noticeable. I have not figured out a smoothing algorithm yet, but that is on my future development list. Since I will mostly be punching the PRESET buttons, the slight jumps don't worry me too much. This may only apply to Hy-Gain's circuit, but that is all I tested for this project.

When a PRESET button is pressed, all PRESET buttons light up as the brake is activated. If the rotator is going clockwise, the CW button is lit to indicate which direction the antenna is going, as long as the rotator motor is powered. The same logic applies to the CCW button. I built in a half-second delay from the time the brake is activated until the motor starts turning. There is also a "coast" concept built in that removes power from the rotator motor 10° degrees before it reaches its PRESET choice. Power to the brake is cut 5 seconds after the motor power is cut in order to protect the rotator from having its brake engaged while the antenna is still moving. This logic may be annoying to the purist, because when you pick NE, for example, it could end up a couple of degrees plus or minus the desired PRESET direction, depending on antenna size, the wind conditions or the antenna's previous direction. The manual CW and CCW buttons can fine-tune the ultimate position as needed, and they use the same brake and motor timing that the presets use. None of the antennas is so sharp that a couple of degrees make a big difference, but I could certainly tighten up the dead band and tolerance, if I wanted to get picky.

You may also be able to see a rotator KILL button on the touch screen shot. I put this in for two reasons: (1) in case I wanted to stop a rotator move started by a PRESET button (eg, I changed my mind after pressing a PRESET) and (2) in case the antenna gets mechanically stuck for some reason. I also put in a 50 second timer as a failsafe, so that the rotator *cannot* operate for more than 50 seconds at a time. Yes, this might mean I need to punch a PRESET button twice to go from southeast to southwest, but the peace of mind is worth it to me.

The nice thing about having a programmable system is that you can change almost anything to suit your taste. I will probably move buttons around or add new ones as I get to operate this system through a contest season or two. The completed panel board holds the PLC, SixPak, terminal strips, StackMatch IIs, A/B switches, relays, power supplies, Internet access point and router.

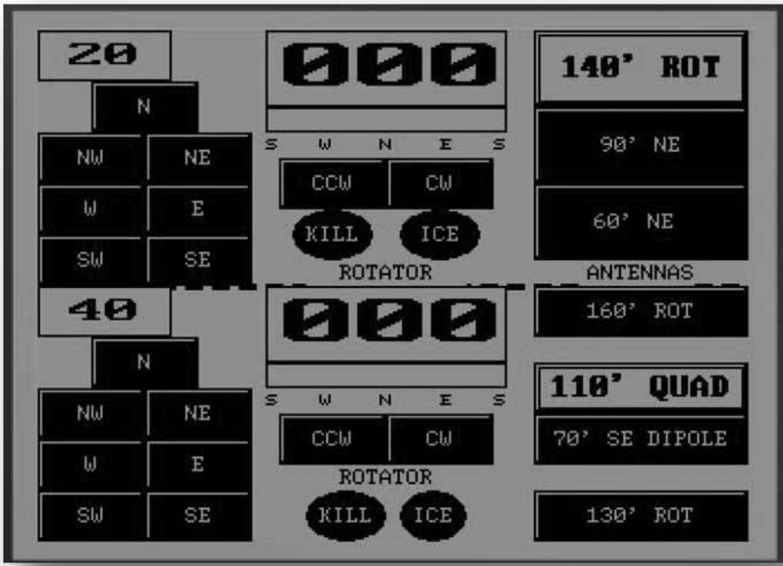

Figure 2 – Typical SO2R Display

You may have also noticed a Variac in the lower left-hand part of the panel. I put this in to adjust the ac voltage that can be sent to the rotators. The Variac is on the primary of a 28 V ac 5 A transformer, so I can adjust the voltage going out to the rotators up to about 32 V ac if needed. I only power the transformer when a rotator is triggered. One rotator cable is about 500 feet long, so it may need a bit of a boost at some point, and I built in the ability to adjust if needed. I scrounged the Variac off eBay for about $20 and couldn't resist using it.

Filtering

Another piece of this project was tying the ICE 419 six-band pass-band filters into the PLC. Since the PLC is basically a large band decoder, I replaced my Elecraft KRC-2 decoders and just tied the ICE filters to the PLC. (The KRC-2s will be on eBay soon.) I also put a small button on the touch screen that allows me to turn the ICE filters off as needed (they default to "on"). This way, I can permanently mount the ICE filters out of the way beneath my operating desk, yet still be able to switch them on or off if needed. I have found occasions when I wanted the ICE filters off (playing on 30, 17 or 12 meters) or listening to WWV), and this worked out great. The ICE filters used sinking PLC modules to operate, but from a programming point of view they are simply I/O points.

Antenna Switching

While I love my Array Solutions StackMatch units, their rotary knob control boxes were troublesome for me during contests. Since I don't currently use any stacking schemes, it was hard to justify spinning that round knob all the time when I selected different antenna combinations. I know Jay, WXØB, sells a master pushbutton controller to replace the rotary knob, but I'm pretty cheap, so I've built that feature into this system. The C-more Micro-Graphic touch screen pushbuttons are perfect for me to quickly select the antenna or antennas I need at the time. The panels confirm selections with a beep (which can be turned off, if desired), and it doesn't take too long to get the hang of the best way to punch the touch screen for fastest selection. The last antenna selections per band are retained as long as the control system stays powered. Since everything is programmable, you could build up a "scenario" button (ie, "EU sunrise") that selects a repeatable combination of antennas and rotator directions for a given need.

Each time I change bands on the K3s, the screen follows and presents all the antennas, rotators, Beverages and filters available for that band. If only a single K3 is powered at the SO2R desk, a single band screen's worth of choices is presented. The single band screen is less crowded than the SO2R screens, which display two bands. If the second rig at the SO2R position is turned on, the screen automatically presents Rig A's choices at the top of the screen and Rig B's choices at the bottom. Your preference may be right and left presentation.

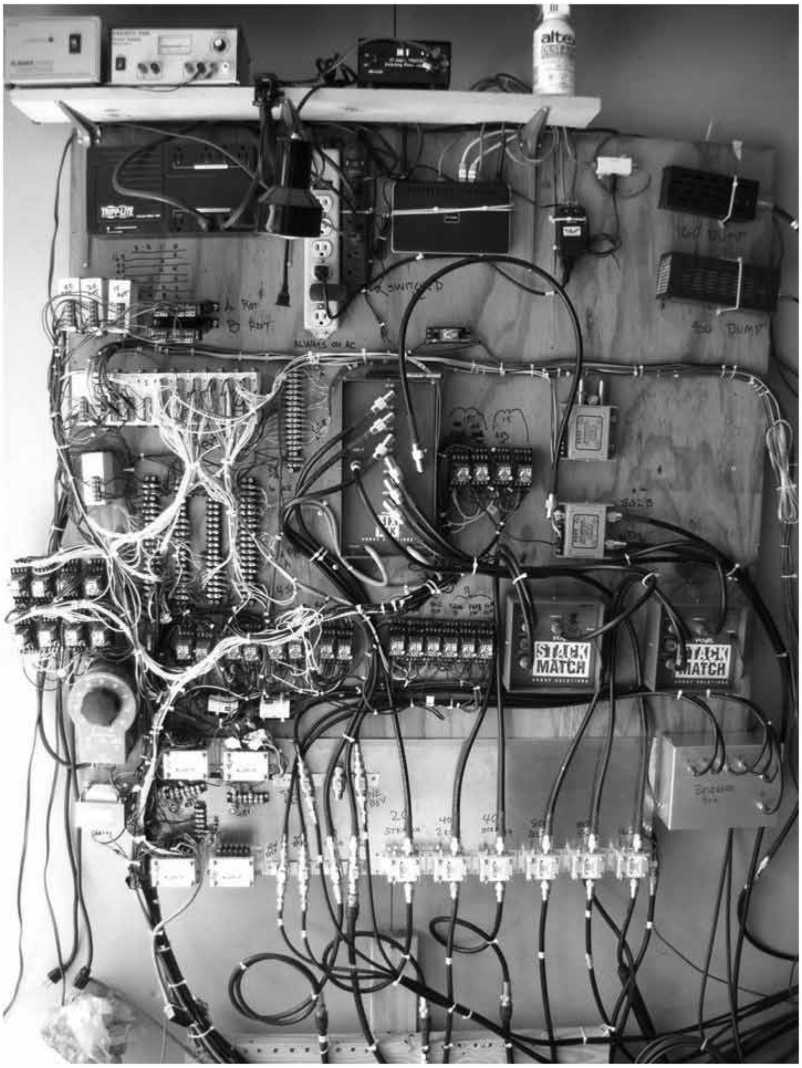

Figure 3 Complete Control Board

Whenever the K3 at the multi-single operating position (Rig C) is turned on, all antennas and rotators that were assigned to Rig B at the SO2R position are immediately moved to Rig C with zero re-cabling. This would be a multi-single configuration as opposed to a single op configuration when Rig C is off. I have room in the PLC to add the ability for both SO2R coax cables to be swapped to the MS position, but that is a future project if needed.

The Comtek switch boxes on 80 and 160 also needed to run through the control system. Again, reverse engineering the relay control logic for these boxes sounds like an easy task, but you really need to keep good notes on the logic map you discover, in order to ensure that you don't have the relays switching incorrectly.

I also protected these switches by sensing when a rig is keyed and not allowing antenna switches to operate until *after* the rig is unkeyed. The CLICK PLC has a nice function that triggers on either contact closure or contact opening, which I used for this application. Although I'm not aware of any issues with burned contacts, I know in the long run that I'll be glad I'm protecting the Comtek and StackMatch switching units outside. This was a fun part of the project, because I learned to use the "interrupt" feature built into the CLICK (and most other PLCs). As you might guess, when an interrupt signal is sensed (eg, a K3 transmit signal from the ACC connector turns on), the PLC program immediately executes the code commanded by the interrupt before moving to the next step of the ladder logic program. In my case, I set the code to block *all* switching functions associated with the RF paths. I tested this out by hitting the TUNE button on the K3 and then hitting an antenna selection button. Nothing happens until the TUNE button is unkeyed and *then* the antenna switches. I now have more peace of mind knowing that my chances of hot-switching a control when I'm dead tired are greatly reduced.

Rig Protection

In order to protect the rigs if both rigs *should* ever end up on the same band, I used the transmit inhibit and transmit sense lines of the K3 as well as a red warning that flashes on the touch screen to alert you to a same-band conflict. The rigs won't transmit when they are on the same band. Both the TX INH and KEYOUT-LP pins are run from each K3 back to the PLC, so I can use interrupts to keep the rigs from transmitting into each other, as well as drive my interrupt lines for other control logic. Even if they could transmit while on the same bands, the RF path switching does not allow a direct connection between any two rigs. The worst that could happen would be a transmitted signal on the open contacts of a relay carrying an RF signal on the opposing contacts.

I also took the opportunity to install lightning protection on each of the coax and rotator cables coming into the control system. I will eventually install lightning arrestors on the StackMatch and Comtek lines as well, but I have not found any hot deals on eBay yet. When the control system is powered down, no antennas are connected to the rigs.

Future Remote Control

Since the control system is locally controlled by an RS-232/485 touchscreen panel, this same link could be used to provide complete remote control over the Internet. With a 60-mile commute to the station, a remote link is high on my project priority plan. I have already purchased the RemoteRig (**www.remoterig.com**) system that Rick, K6VVA, described in his article, "How *Not* to Build a Remote SO2R Contest Station — Part 1" (January/February 2010 *NCJ*).

The RemoteRig boxes are far superior in speed and function over any VoIP software I've tried previously. Glenn Anderson, WB5TUF, also gave me a Digi Port Server that I plan to marry with the RemoteRig boxes in my system. The server provides eight RS-232 channels from a single IP port. These tools will provide the basis for a dandy system that may allow me to compete in CW contests remotely. I'll have a future article if that project is successful.

My deepest thanks to K5TU and WB5TUF for their ideas, support and donated equipment that contributed to bringing this project to life, and, of course, to W5SJS for having the patience to let me commandeer his garage while I assembled this beast. I'll be sweeping up wire insulation clippings for years, because there is approximately 600 feet of hookup wire connecting all the modules, relays and terminal strips. More photos are available at **http://picasaweb.google.com/so2rso2r/NCJBandDecoderArticle#**.

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