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An Eight Channel Remote Control Antenna Selector

*Select between eight antennas or feed one antenna to any of up to eight radios.
With better than 70 dB of port-to-port isolation, you can be sure
the signal is going where you want it to.*

A few years ago, my friend Joe Spinks, AA0KW, and I started building and experimenting with Double Bazooka antennas. I decided to build two 20 m and two 40 m antennas for my antenna farm. My plan was to deploy a 20 and 40 m Double Bazooka facing East-West and a 20 and 40 m Double Bazooka facing North-South. These, along with a vertical antenna and two G5RV antennas I already had mounted, quickly gave me a cabling and switching problem. Also, Joe pointed out that my wife may not appreciate me punching seven more holes in our house and running a sizable bundle of coax across my basement to my station. Even if I could do all that, manual switching wasn't practical between that many antennas. I would be constantly connecting and disconnecting antennas when I wanted to change directions or bands.

That's when I decided to design a remote control antenna selector to select between eight antennas. I am currently a Systems Engineer but have degrees in both Electrical Engineering and Software Engineering. In addition, I have electronic circuit design and printed circuit board layout experience. Joe is also an electrical engineer, and has designed automatic antenna tuners for our company and has extensive RF circuit design experience. So creating and testing a viable design was not a technical concern. The main question then became, what improvements could be made over the existing products. The answer came quickly: Isolation between the selected and other antennas! Wouldn't it be nice to select one antenna and not get interference from another antenna?

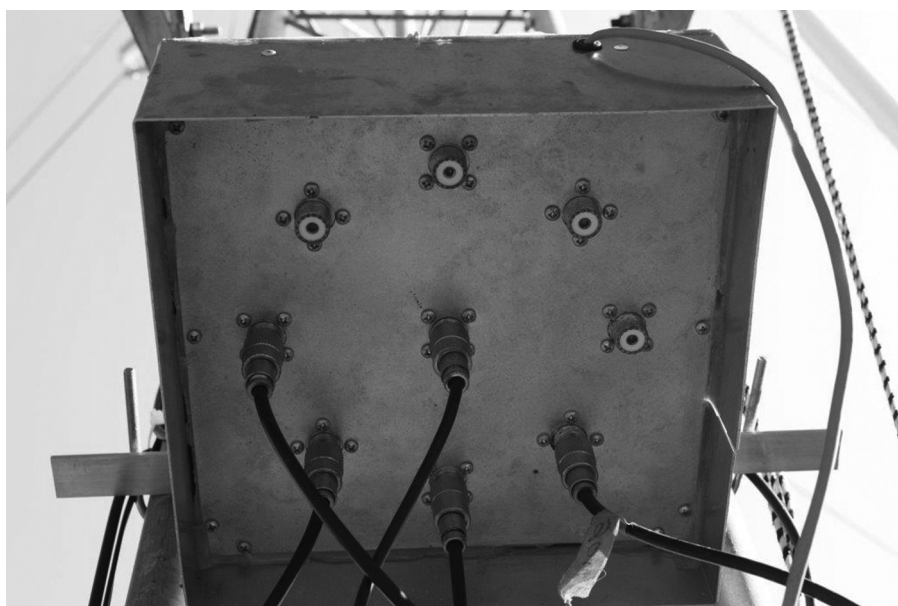


Figure 1 — The remote antenna selector board is mounted on the side of my tower. As shown here, it is selecting between four antennas.

We achieved greater than 70 dB of isolation between antenna ports, as shown in the test plots included with this article. There are several design techniques that helped us achieve this kind of isolation: Two relays were used in each signal path to double isolate the antenna from the radio input. The traces that make up the RF path were designed as a coplanar waveguide. The RF connector placement on the circuit board was tightly controlled to be symmetrical to make the RF electrical paths identical. RF trace routing followed good design practices

by limiting angles to 45°. Control traces were routed on the bottom of the circuit board to maximize ground plane continuity. For our switch, we selected control trace widths of 15 mils for better current capacity.

Implementing the Design

I mounted a switch assembly on my tower and connected four antennas to the assembly as shown in Figure 1. My home station consists of an Icom IC-706 MKIIG rig, with an LDG tuner and our remote

control antenna selector, as shown in Figure 2. The remote controller is shown in the lower left. Switching between eight antennas is just a matter of twisting the rotary switch. The real story is the isolation between antennas. Figure 3 shows the IC-706 S meter displaying S6 when an antenna is selected. Figure 4 shows the IC-706 S meter displaying blank when an unused port is selected.

One evening in my “Lab,” Gregg Lind, KCØSKM, noticed my design and board layout. Gregg and I have been collaborating on a remotely deployable solar powered Weak Signal Propagation Reporting (WSPR) station using a Netduino. Gregg immediately saw multiple applications for our project and had me present it to both of our local clubs, Cedar Valley Amateur Radio Club (CVARC) and Collins Amateur Radio Club (CARC) here in Cedar Rapids Iowa. He quickly took orders from 20 hams that were interested in purchasing our project if we offered it as kit. The kit was then featured during one of our club’s annual kit build nights.

The project was a big hit with both clubs. It turns out that I was not the only one grappling with antenna management. Besides, many amateurs like to build kits. Gregg used this success to convince me to write this article to invite collaboration from other Amateur Radio enthusiasts throughout the ham community.

Later, Gregg used our switch to solve a radio and antenna management problem in our club’s shack. Our club has multiple radios and multiple antenna options, which require an operator to trace cables behind a huge rack and make the connection manually. Automatic selection of radios and antennas would make the station much more user friendly. The application required two remote controlled antenna selectors, one to select a radio connected to another antenna selector that picks the desired antenna. Since the installation, our station

usage has increased dramatically. The first switch selects one of eight radios, the second switch selects one of eight antennas. Figure 5 shows the two RF switch assemblies used in the CARC (NØCXX) station. Currently the assembly is managing the selection of four radios to six antennas.

Design Details

The remote control antenna selector consists of a switch assembly and an optional remote controller assembly.

The switch assembly contains the relays and relay drive circuitry to select between position 0 to 7. The assembly only requires a 13.8 V dc supply and a 3-bit TTL signal to input for the switch selection. This interface

allows for a variety of remote control solutions. Figures 6 and 7 show the bottom and top views of the RF switch assembly.

A remote controller assembly was designed as a simple solution for my station. The remote controller assembly consists of an eight position rotary switch and an 8-to-3 digital encoder connected to 2N2222A transistors to drive the switch assembly via a standard CAT-5 eight wire cable. The remote controller Assembly is shown in Figure 8.

As mentioned earlier, one major design consideration was to minimize RF coupling between antenna channels. Therefore, it was essential to follow the rules and principals of good basic RF/Microwave design.

The switch assembly features a coplanar



Figure 2 — This photo of my operating position shows my power supply, LDG Autotuner, and Icom IC-706 MKIIG radio. The antenna selector control panel is mounted behind a block of wood to match the operating position shelf. You can see the selector shaft, with the first of eight LEDs illuminated to show which antenna has been selected. I still have to add labels below the LEDs to help identify the antennas.



Figure 3 — Here is a close-up of the Icom radio display. Notice that with a 40 m antenna connected, the S meter is showing an S6 signal.



Figure 4 — In this close-up of the Icom radio display, there is no antenna connected. In this case, the S meter is showing no signal.

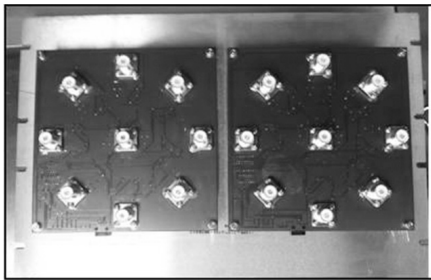


Figure 5 — This photo shows the two RF switch assemblies used in the Collins Amateur Radio Club (NØCXX) station. The assembly is managing the selection of four radios to six antennas in the club station.

waveguide design for all RF traces, tuned to a $50\ \Omega$ impedance with ground plane stitching that ensures maximum isolation between ports.

Complete impedance (Z_0) matching ($50\ \Omega$ in to $50\ \Omega$ line to $50\ \Omega$ out) minimizes return loss and SWR. A coplanar waveguide design was chosen so that the trace impedance on the circuit board could be matched to the input and output impedances. In a coplanar waveguide design, Z_0 is a function of signal conductor width & thickness and a function of the dielectric constant (ϵ_r) of the material surrounding the signal conductors.

Signal return currents follow the path of least impedance. In high frequency circuits this equates to the path of least inductance. Stitching the ground planes with vias every 0.1 inches or so around each RF trace helps minimize the inductance in the signal return path by virtually creating a waveguide on the circuit board.

The RF connectors were placed symmetrically around the output connector (located in the center of the assembly) to ensure an equal electrical length for each RF path. Typical isolation measured between ports is greater than 70 dB.

Extensive RF decoupling on the power and control lines was added to provide maximum RF decoupling from the control signals. I added transient-voltage-suppression diodes (Transorbs) on all input control lines for good surge protection.

The project begins with a schematic program to capture the logical design. I chose *TinyCAD* for my schematic capture and *Free PCB* for the circuit board layout and trace routing. Both tools are easy to use and use the same net list format.^{1,2}

The switching relay is the heart of this design. We chose an Omron Electronics Inc G6RN-1-DC12, which is a sealed double pole double throw (DPDT) relay with 8 A silver

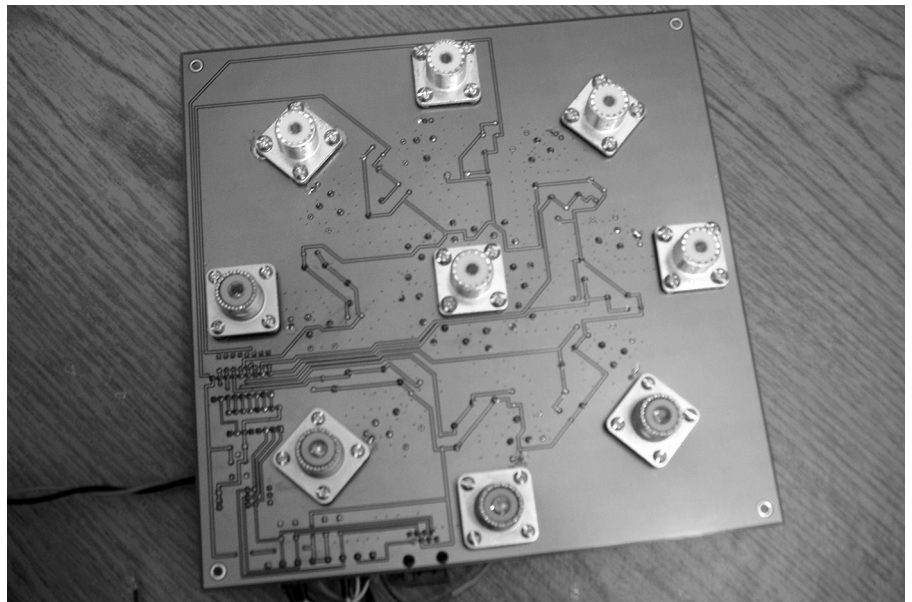


Figure 6 — Here is a close-up of the SO-239 connector side of the antenna selector circuit board.

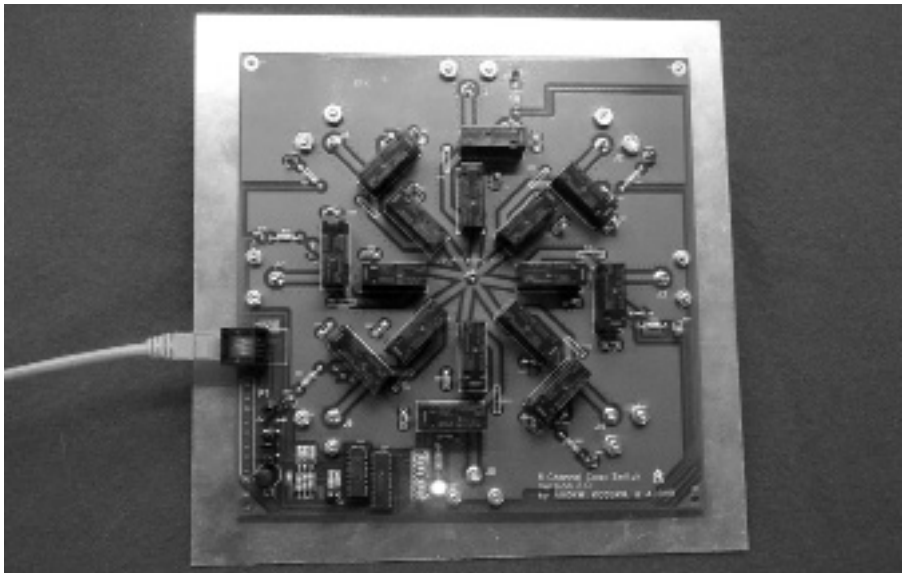


Figure 7 — This photo shows the relays and the circuit board traces that form the coplanar waveguide.

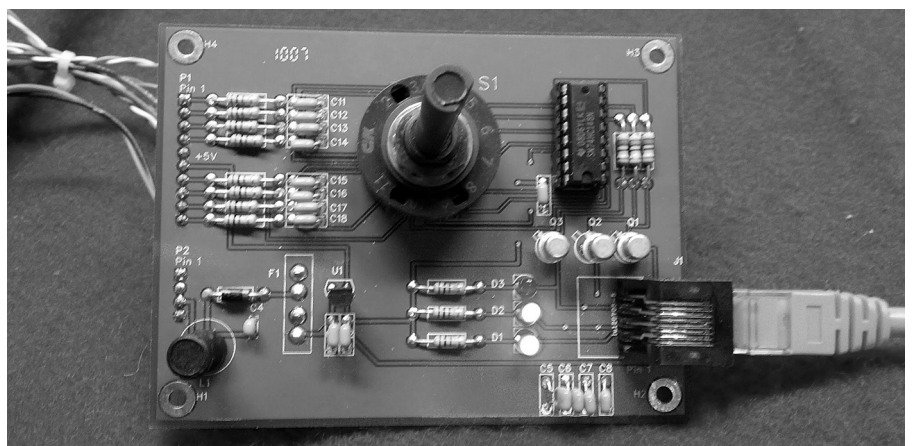


Figure 8 — This photo shows the antenna selector control board.

¹Notes appear on page 17.

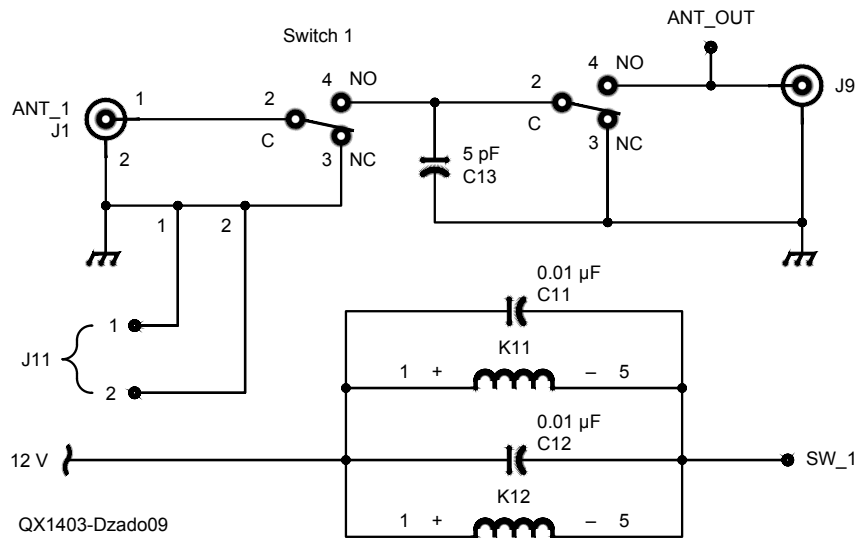


Figure 9 — The schematic of the basic selector switch operation. The normally closed side of the relay grounds the antenna when it is not selected. The second relay serves to isolate that antenna port from the output signal on a selected antenna.

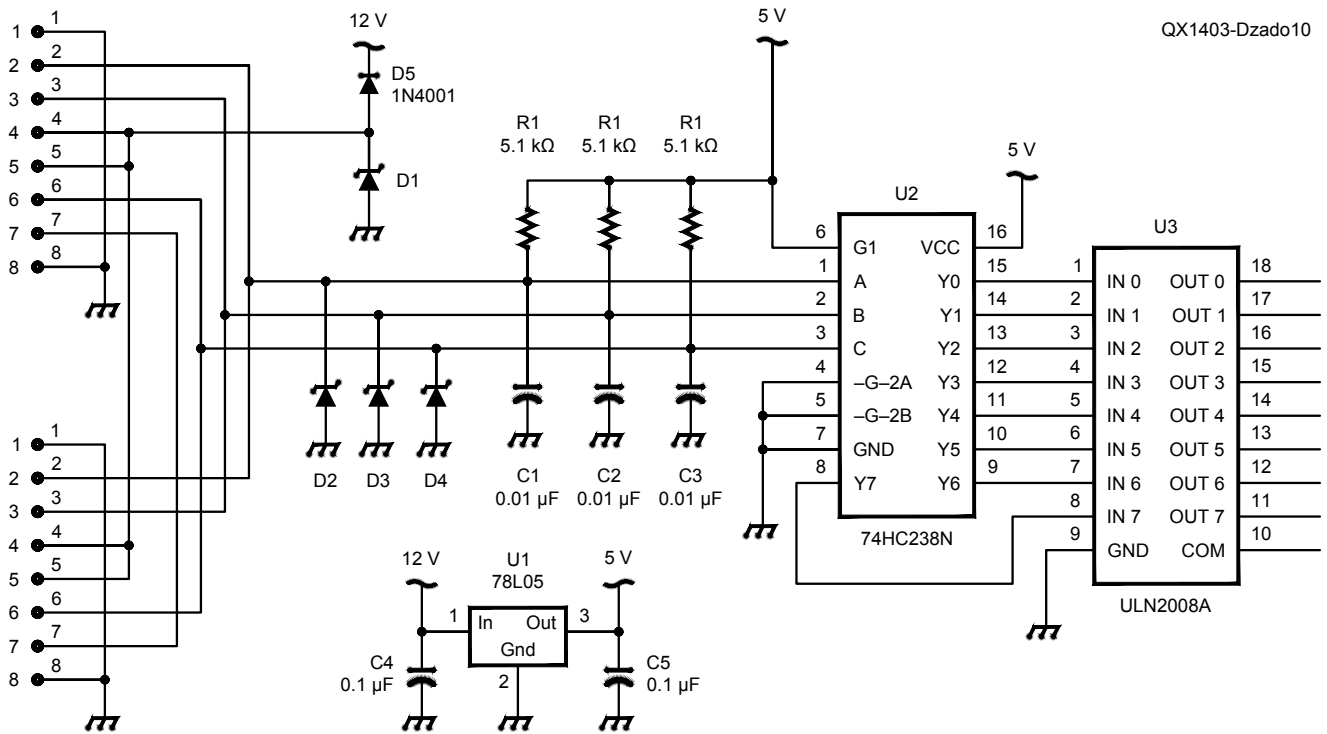


Figure 10 — The schematic of the antenna selector control logic. U2 is a 74HC238 3-to-8 decoder IC and U3 is a ULM2008A high current, 8 pair Darlington transistor array to provide the relay drive current.

over gold contacts. The contact capacity is more than adequate for our design. We chose to double isolate each RF port by using two relays in each path. As shown in Figure 9, the first relay will ground the antenna input when de-energized. The second relay simply isolates the RF port from the output.

The switch control logic incorporates a simple 3-to-8 decoder (74HC238) and a high current, eight-pair Darlington transistor array (ULM2008A) to provide the relay drive current, as seen in Figure 10.

Topologically speaking, a coplanar waveguide design offers better isolation between signals versus a microstrip design. Even though a microstrip design is easier to layout, Joe and I opted for maximum isolation between antennas.

The RF path design starts with the basic power equation to determine the trace width to handle the transmit current.

$$P = I^2 Z_0 \quad [\text{Eq 1}]$$

then solving for I:

$$I = \sqrt{\frac{P}{Z_0}} \quad [\text{Eq 2}]$$

Then for a 100 W transmitter into a 50 Ω load we have:

$$I = \sqrt{\frac{100 \text{ W}}{50 \Omega}} = \sqrt{2} \text{ A} = 1.4 \text{ A}$$

Using the *AppCAD Coplanar Waveguide Calculator* by Avago Technologies, I set the known dimensions of the circuit board and adjusted the trace width, W, and gap, G, until $Z_0 = 50 \Omega$, or there about, as shown in Figure 11.³ I chose the trace width of 115 mils and a gap of 100 mils as a good combination for the 100 W circuit boards. Note that other combinations of trace width and gap will also result in a Z_0 of 50 Ω . For example, a trace width of 125 mils and a gap of 250 mils would also work, but that requires quite a bit more space on the circuit board.

Referring to Table 1 for the circuit board trace current capacity, a 115 mil trace is adequate for this design. You can see that at 100 W, the trace temperature rise will be considerably less than 10°C. In fact, with a power of 1000 W into a 50 Ω load, the current would be 4.47 A, so these traces can handle that power with only about a 10°C temperature rise.

Figure 12 shows the printed circuit board component placement and trace routing.

I used an HP-8753D Network Analyzer to test the completed circuit board. Measurements were taken between all eight channels for port-to-port isolation, insertion loss, and SWR.

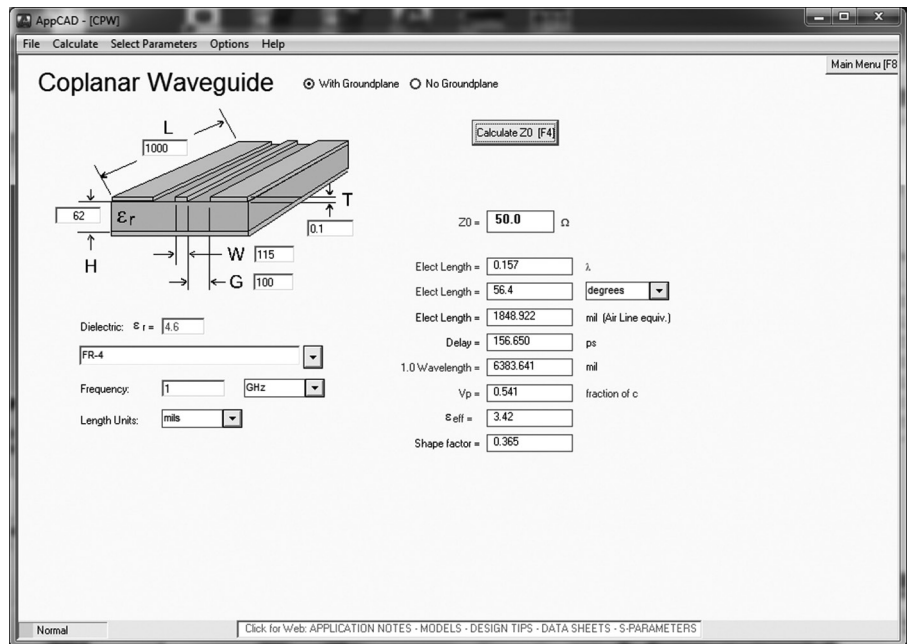


Figure 11 — This is a screen shot of the *AppCAD Coplanar Waveguide Calculator*. I set the following parameters: Circuit Board Material = FR-4, W (Trace Width) = 125 mils, H (Circuit Board Thickness) = 62 mils. Then I adjusted the trace width (W) and the gap between the traces (G) until the calculated Z_0 came to 50 Ω . A width of 115 mils and a gap of 100 mils gave the desired impedance. Other combinations of those dimensions may also result in a 50 Ω impedance, but this combination gave a reasonable trace width for the power handling capability that I wanted.

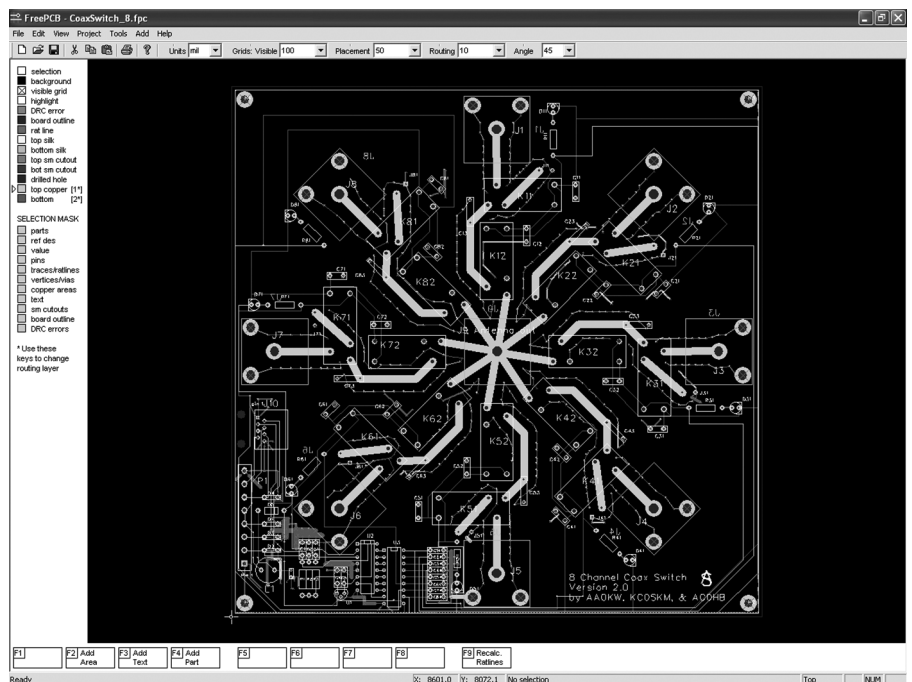


Figure 12 — This is the parts-placement view of the antenna selector circuit board. It also illustrates the coplanar waveguide traces.

Figure 13 shows the test results for port to port isolation between channels 1 and 2. Figure 14 shows the insertion loss for port 1 and Figure 15 shows the SWR for port 1.

The test plots for the remaining ports are almost identical to the port 1 test results. This is due to the coplanar waveguide topology for the RF traces and the symmetrical RF component placement.

Specifications

- **Power Requirements:** 13.8 V dc single power supply at less than 75 mA.
- **Control Line:**

- Minimum 5-wire connection (2 power, 3 control lines) or
- Standard CAT-5 cable (8 wire) interconnect between RF Switch and Remote Controller.
- **Switches:** Sealed RF Relays, Contacts are silver over gold for an 8 A contact rating.
- **Status LED indicators:** on both the switch and remote control assemblies.
- **Impedance:** 50 Ω .
- **Connectors:** SO-239 Silver plated Teflon connectors.
- **RF Power:** 1000 W over 2:1 SWR.
- **SWR:**

- At 30 MHz, < 1.12:1
- At 50 MHz, < 1.23:1
- **Port to Port Isolation:**
 - At 30 MHz, < -75 dB
 - At 50 MHz, < -70 dB
- **Insertion Loss:**
 - At 30 MHz, < 0.10 dB
 - At 50 MHz, < 0.16 dB
- **Dimensions:**
 - Switch Circuit Board: 8 x 8 inches.
 - Enclosure: 9.5 x 9.5 x 2 inches.
 - Remote Controller: 3 x 4 inches.

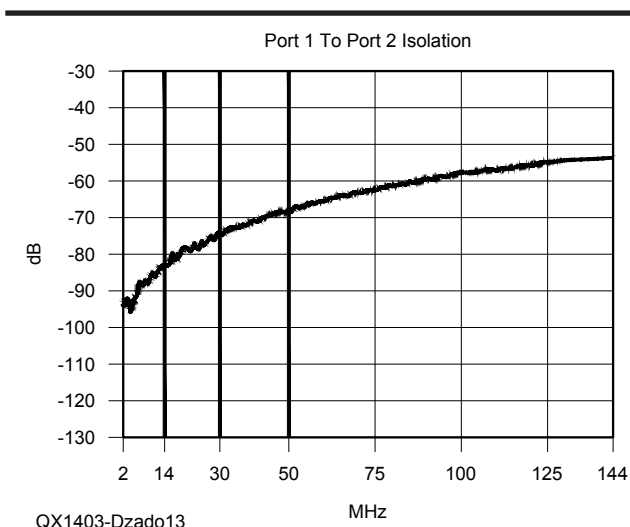


Figure 13 — This graph shows the port-to-port isolation between positions 1 and 2 versus frequency. The test plots for the remaining ports are virtually identical.

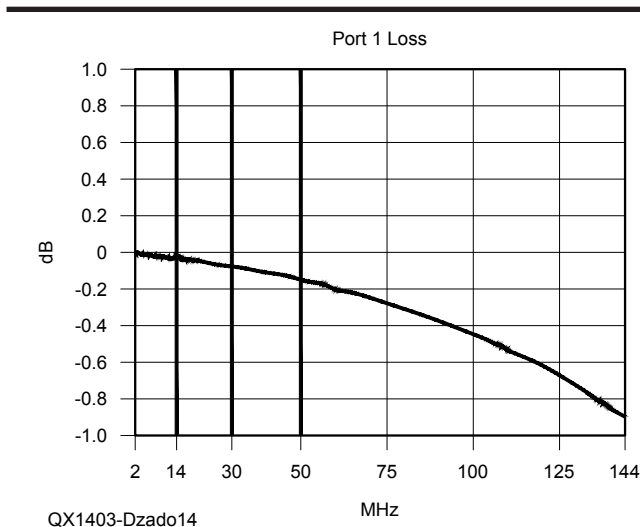


Figure 14 — This graph shows the signal response (S_{11} parameter) versus frequency for port 1. The responses for the other ports are virtually identical.

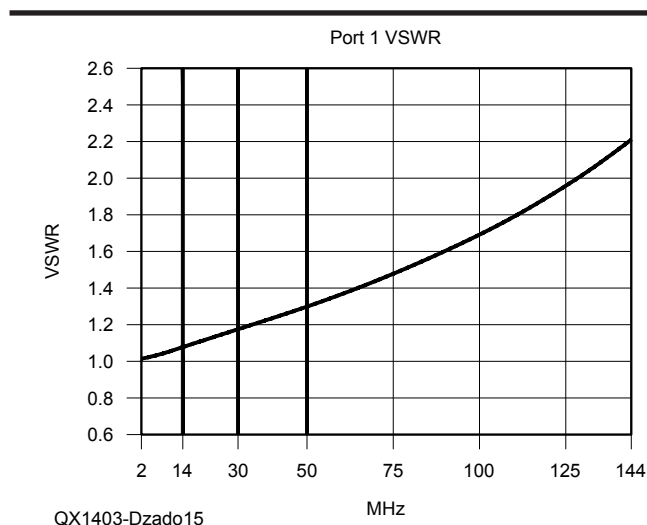
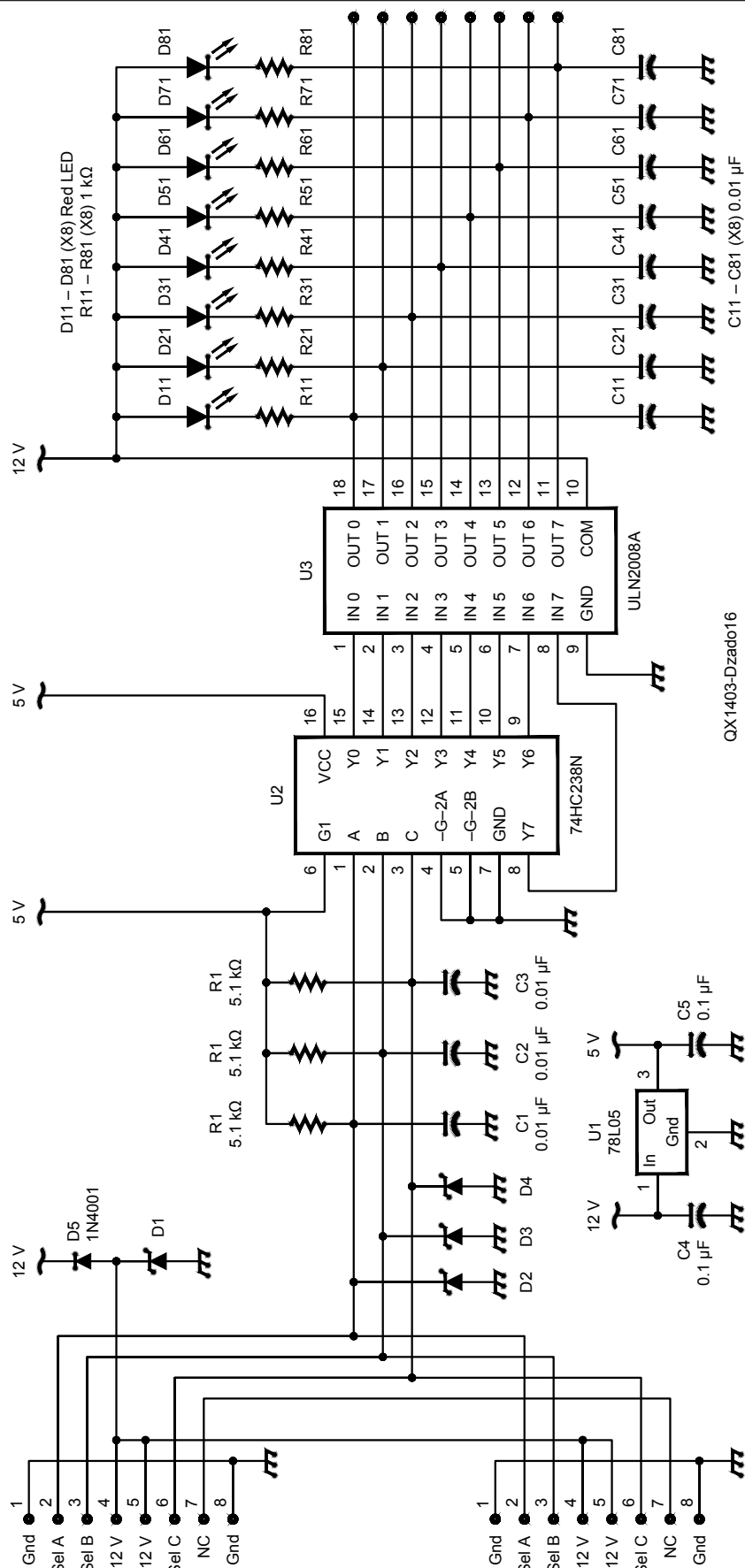


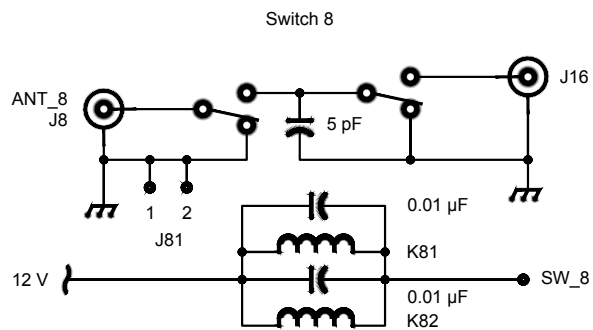
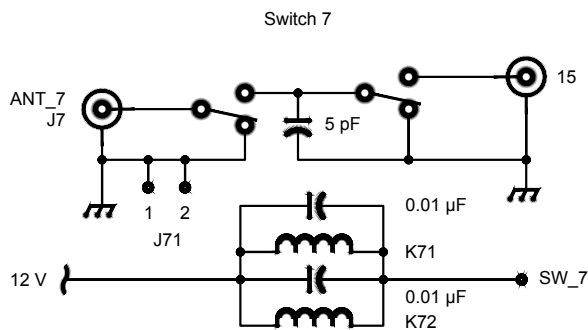
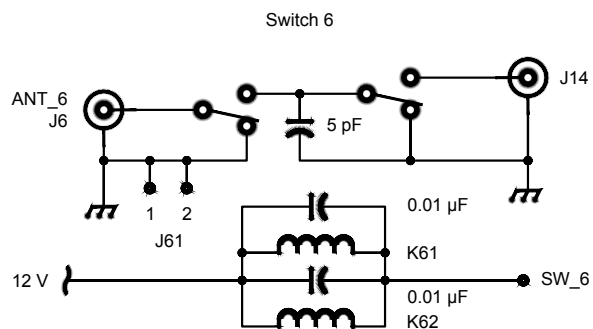
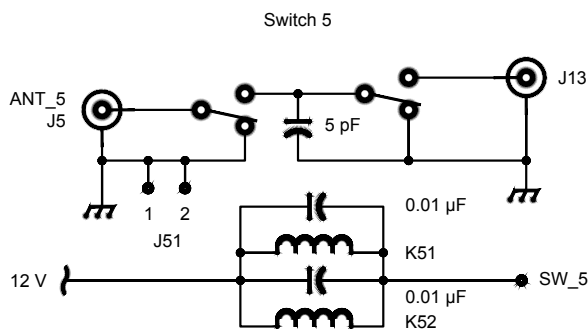
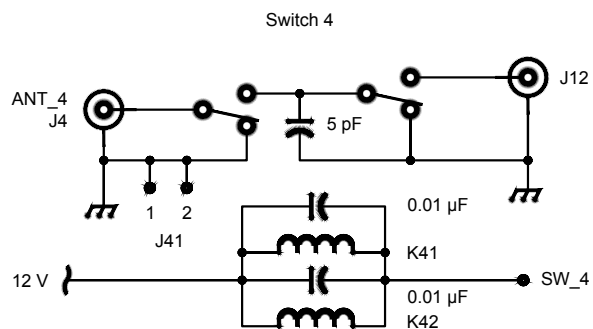
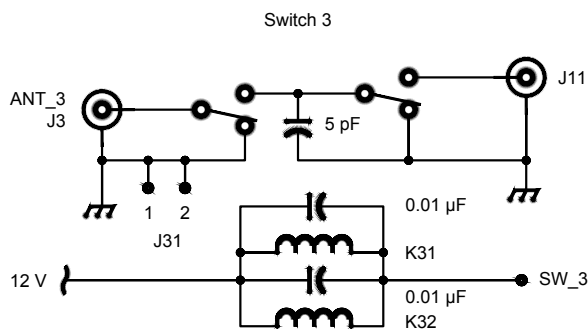
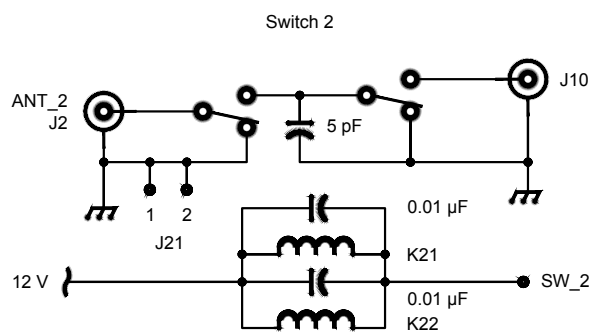
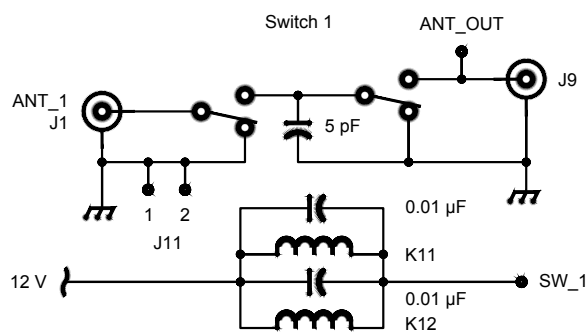
Figure 15 — Here is the SWR response versus frequency as measured for port 1. The other ports have the same response.

Table 1
Circuit Board Trace Widths

Temp Rise Width (mils)	10°C Max Current (A)	20°C	30°C
10	1	1.2	1.5
15	1.2	1.3	1.6
20	1.3	1.7	2.4
25	1.7	2.2	2.8
30	1.9	2.5	3.2
50	2.6	3.6	4.4
75	3.5	4.5	6
100	4.2	6	7.5
200	7	10	13
250	8.3	12.3	15

Figure 16 — This schematic shows the control wiring and the antenna selector wiring for all eight antenna positions.





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Mike Dzado, ACØHB, obtained his Amateur Extra Class License in 2007. Mike has over 35 years combined experience as an Electrical and Software Engineer, which includes CAE/CAD experience. Mike started his career as an Electronic Technician with the USAF and currently is a Senior Systems Engineer for Rockwell Collins Air Transport Large Display Systems. Mike holds an Associate Degree in Meteorological Equipment from the Community College of the Air Force (1978), Bachelor of Science in Electronic Systems Management from Southern Illinois University (1980), Bachelor of Science in

Electrical Engineering from the University of Utah (1984), and a Master of Science in Software Engineering from the National Technological University (1994). Mike's career experience includes Power Supply Design, Communications Protocol Software Development, Computer Aided Engineering Design and Analysis Tool development, and Software Defined Radio development.

Mike's other hobbies include weather spotting, and designing and building electronic kits for fellow club members. He is a member of the Cedar Valley Amateur Radio Club (CVARC) and Collins Amateur Radio Club

*(CARC) See his website, **www.AC0HB.com** for some of his current projects.*

Notes

¹Learn more about *TinyCAD* and download the program free at: **tinycad.en.softonic.com/**.

²For more information about the *Free PCB* program and to download the installation files, go to: **www.freepcb.com/**.

³You can download the *AppCAD* design software free from the Avago Technologies website. Go to **www.avagotech.com/pages/appcad**.