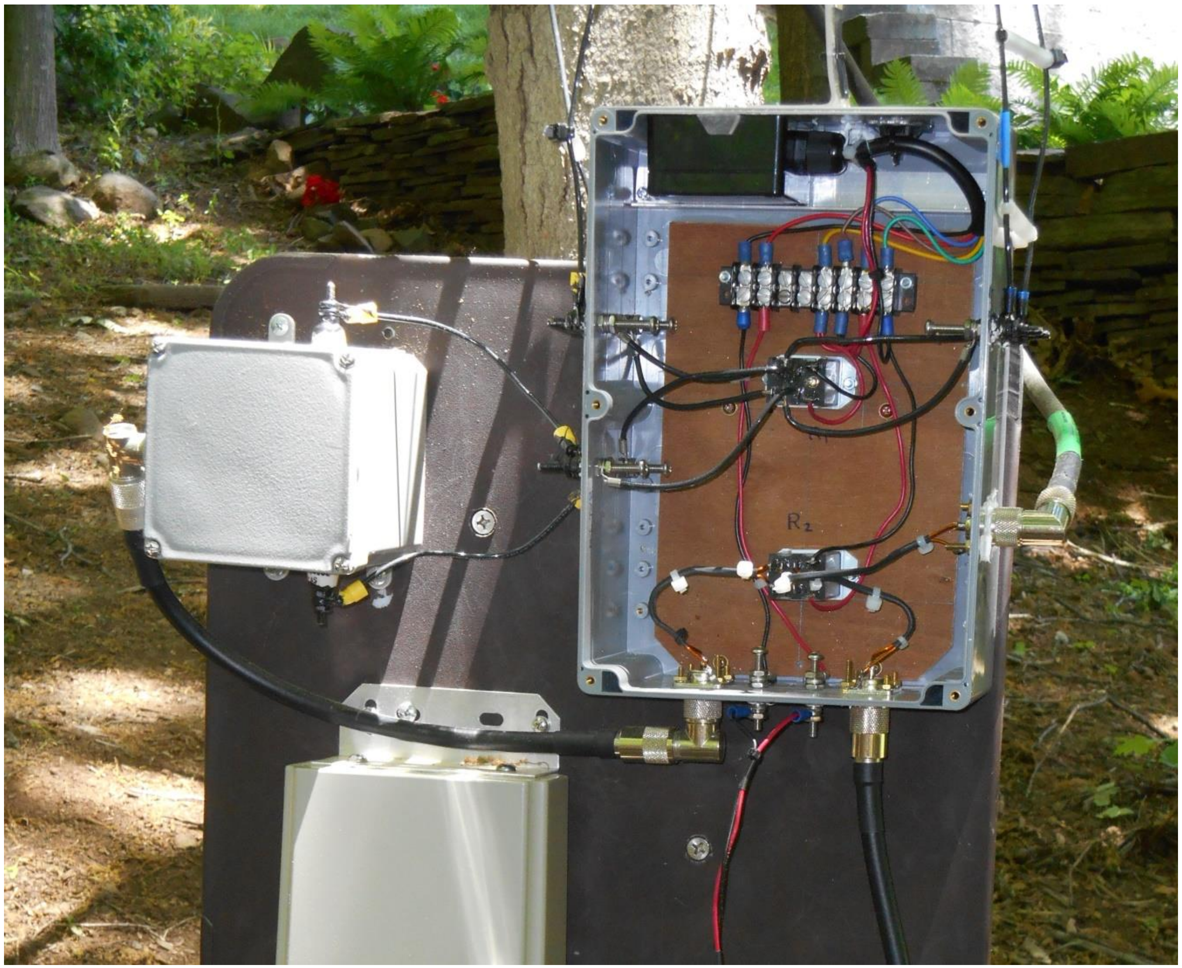
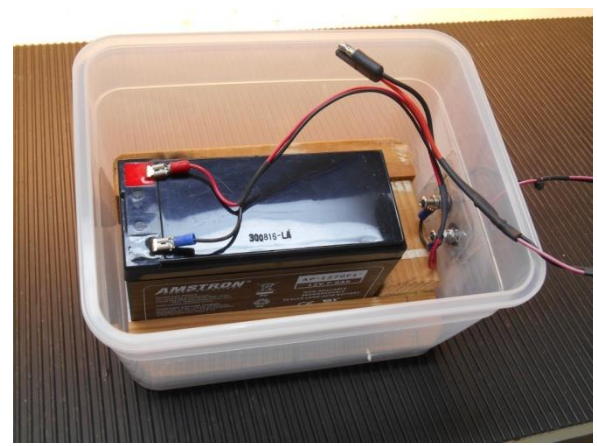
A Wireless Three-way Antenna Switch & Display





by
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Agenda

- Introduction
- Switch Box Requirements
- Switch Box Design
- Switch Box Construction
- Power Handling Capability
- Antenna Selection Display
  - Requirements
  - Design
  - Construction
- Conclusions

Introduction

A weatherproof coaxial switch

- The motivation for this project is due to the HOA restrictions in my townhouse community
- I was able to run a single RG-213 cable between the townhouse and my Quad Vertical Array (**Ref. # 1**)
- In 2015 I added a dipole in an attempt to get some directionality
  - Options for switching antennas are mechanical or wireless
  - I weatherproofed a Diamond CX310, mechanical coaxial switch [**Ref. #2**]
  - The weatherproofing worked well but the switching lacked convenience
- In 2017 I decided add a second dipole and change the switching approach to allow me to
  - select one of the three antennas
  - switch my balun between the dipoles
  - perform all of this from the comfort of my shack.

Ref #1: Stan Ekiert, K3KKH, A Stealthy Vertical Antenna, QST , Aug 2016, pp 37-40
Ref #2: Stan Ekiert, K3KKH, Weatherproofing a Coaxial Switch, Hints and Kinks, QST, Feb 2017, pp 70-71

Requirements

- Use wirelessly technology to select one of three antennas from my basement-level shack (below ground) to a switch panel 55 feet away
- Withstand all weather conditions: driving rain, ice and snow, and freezing temperatures
- Operate remotely from a 12 volt battery
- Operate at the full legal power on SSB (50% operator duty cycle)
- Operate HF through 6 meters
- Display the selected antenna

Switch Box Design

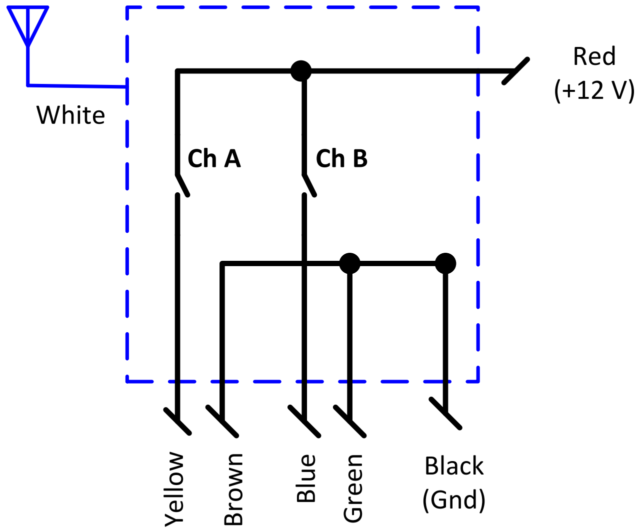
- Use a wireless relay to select one of two, high-current capacity, power relays. The power relays, capable of handling full legal limit, would then perform the actual balun and antenna switching.

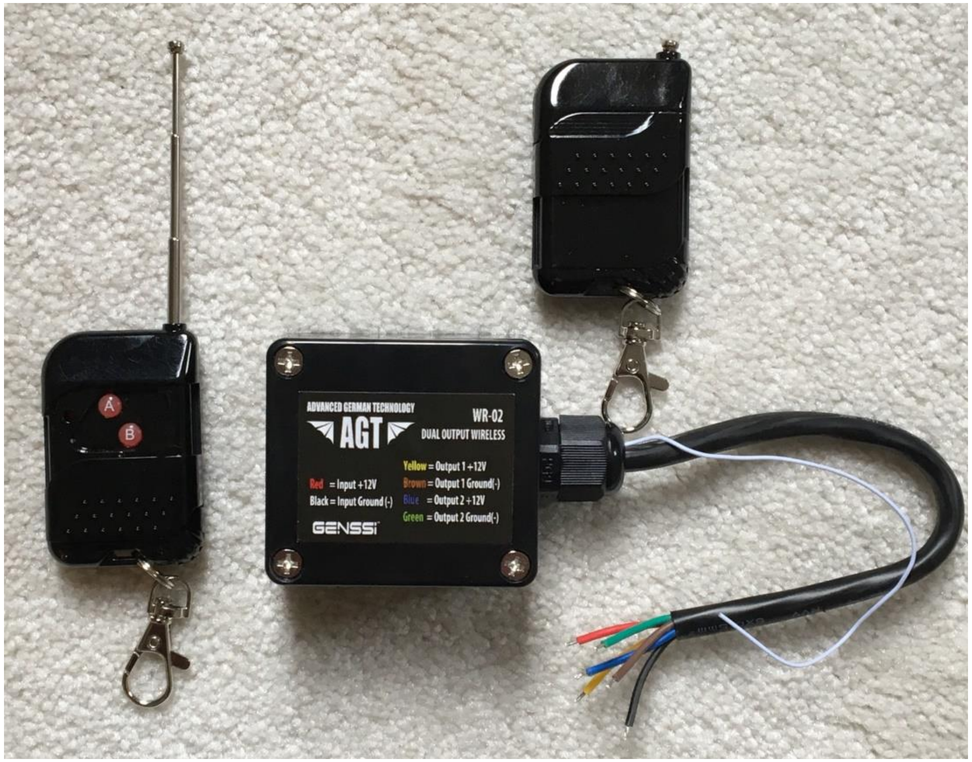
- This approach requires a dual-channel wireless relay, with one channel assigned to each power relay.

- **Wireless Relay**: 2 Channel DC Wireless Receiver & Transmitter, model WR-02, manufactured by AGT (All German Technology).

WR-02 Wireless Relay

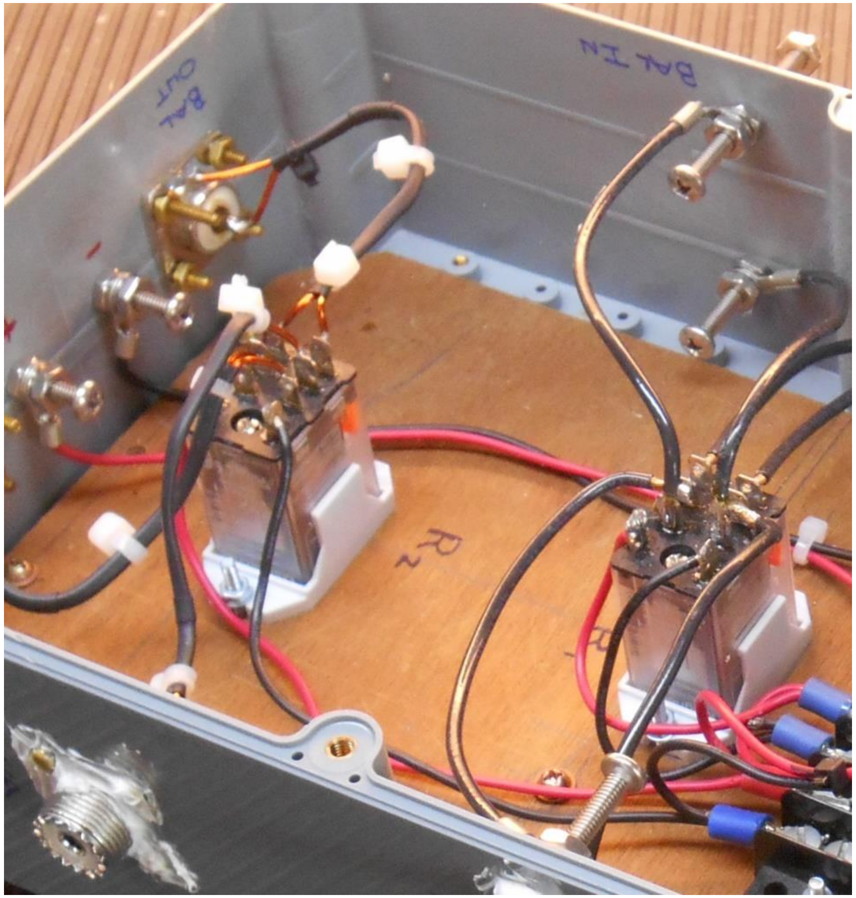
- The unit contains two remote controls (transmitters), and one receiver
- Uses an 8-bit encoding scheme
- Multiple receivers can be programmed to respond to a common set of controllers
- Transmits at 315 MHz with an advertised range of 150 feet
- Each receive channel is capable of independently switching 5 amps at 12 volts DC
- Pull-in Voltage = 8.4 volts
- Drop-out Voltage = 4.2 volts
- No-load current = 50 ma/channel
- Controllers are powered by a single 23A, 12 volt alkaline battery
- Receiver is $2\frac{1}{2}\ x\ 2\frac{1}{4}\ x\ 1\frac{3}{8}$ in.





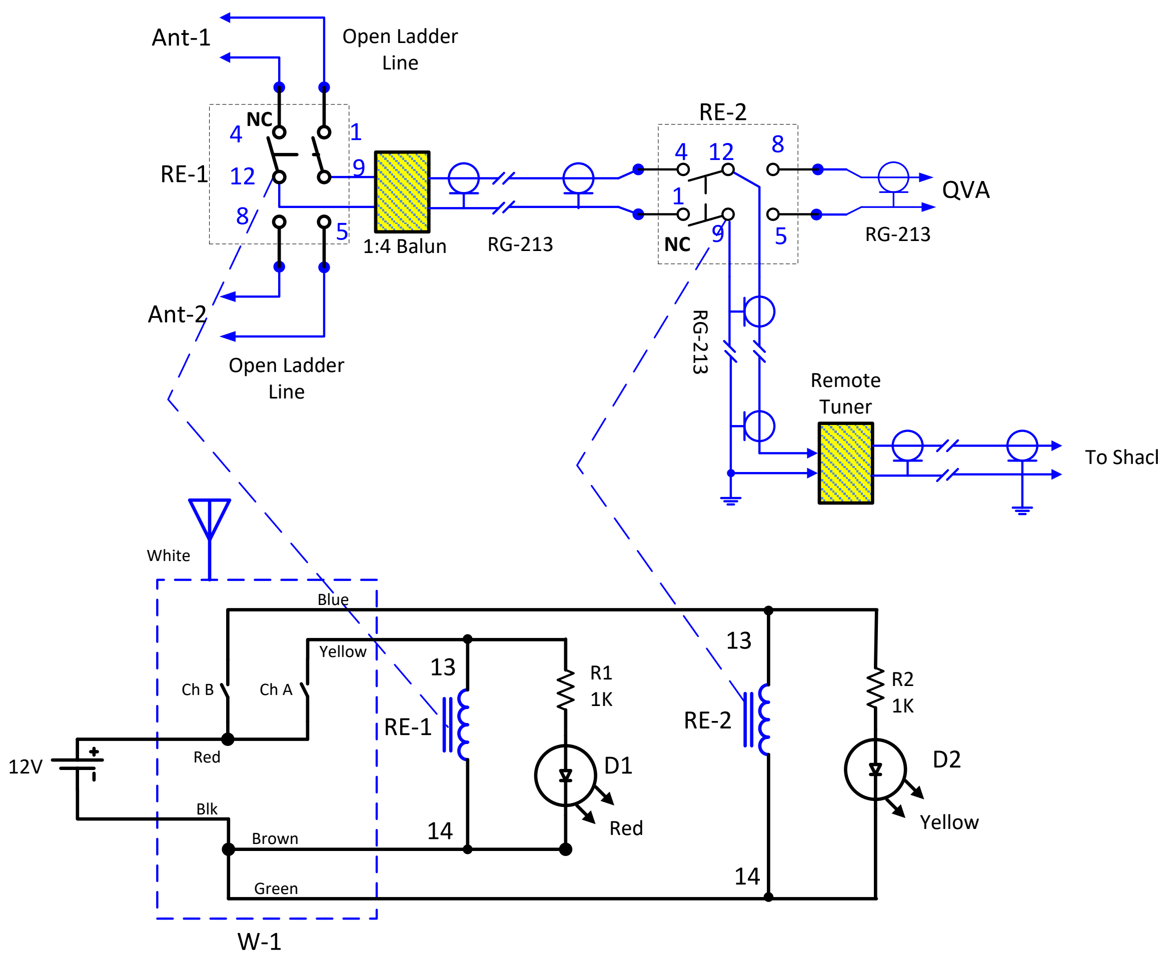
Power Relays

12 volt DC double-pole double-throw, 700 Series Magnecraft “Ice Cube” Power Relays and Mounts, models 782XBXC-12D and 16-782C1



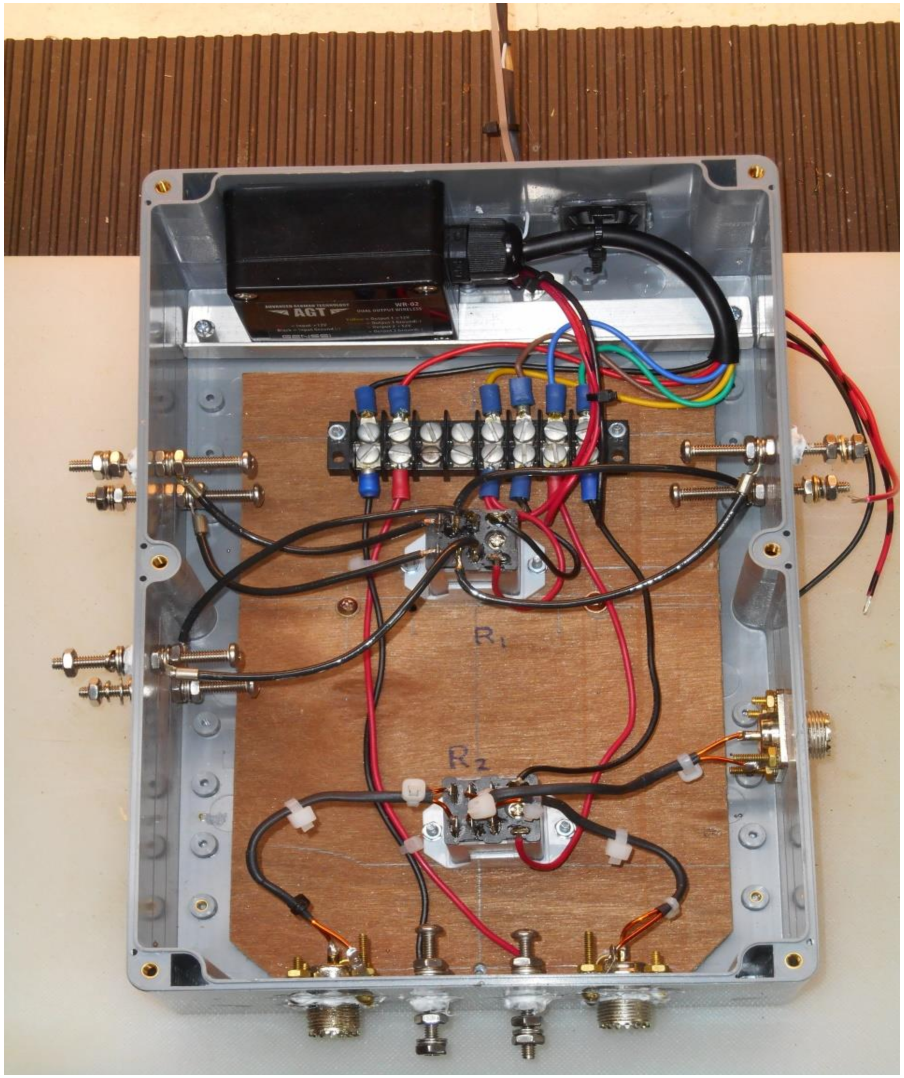
- Relays can be operated in any orientation
- The AC contact rating is 15 amps
- Pole-to-pole dielectric rating of 2500 volts rms (3535 volts peak)
- Pull-in Voltage = 9.6 volts
- Drop-out Voltage = 1.2 volts
- No-load current = 75 ma
- Dimensions: 1.5” x 1.06” x 1.1”

Switch Box Schematic



- When the relays are un-powered Antenna-1 is connected to the Shack
- RE-1 switches the dipoles. RE-2 selects either the dipole leg or QVA
- The maximum current draw, with all relays and LEDs active, is 275 ma.

Switch Box Construction



- 10 ¼” x 7” x 4”, Velleman G378, PVC enclosure. The cover (not shown) is gasketed for a waterproof fit.
- All hardware is 8-32 stainless, except for the 4-40 brass hardware used to mount the SO-239 connectors
- AWG #14 THNN wire was used to connect RE-1 to its Ports
- 4.5” long, 50 ohm transmission lines made from AWG #16 Formvar wire were used to connect RE-2 to its Ports. These are all 50 ohm ports.
- The transmission lines were built by placing two Formvar wires parallel to each other and securing them with heat shrink tubing and tie-wraps

Parallel Wire Transmission Line

- ❑ Characteristic Impedance of a parallel wire transmission line is

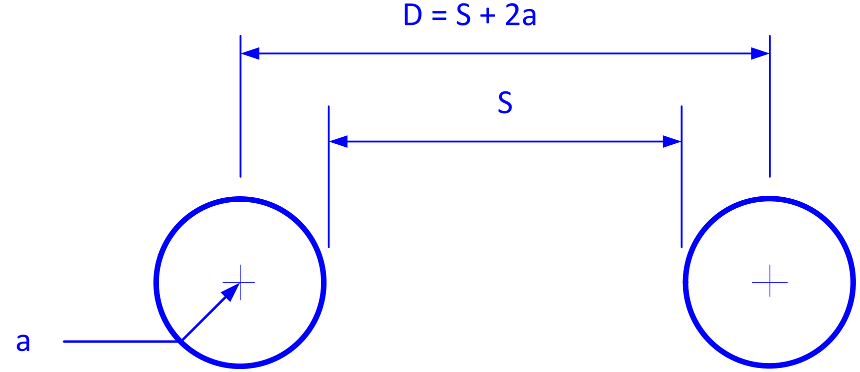
$$Z_0 = \frac{120 arcosh(D/2a)}{\sqrt{\varepsilon_r}}$$

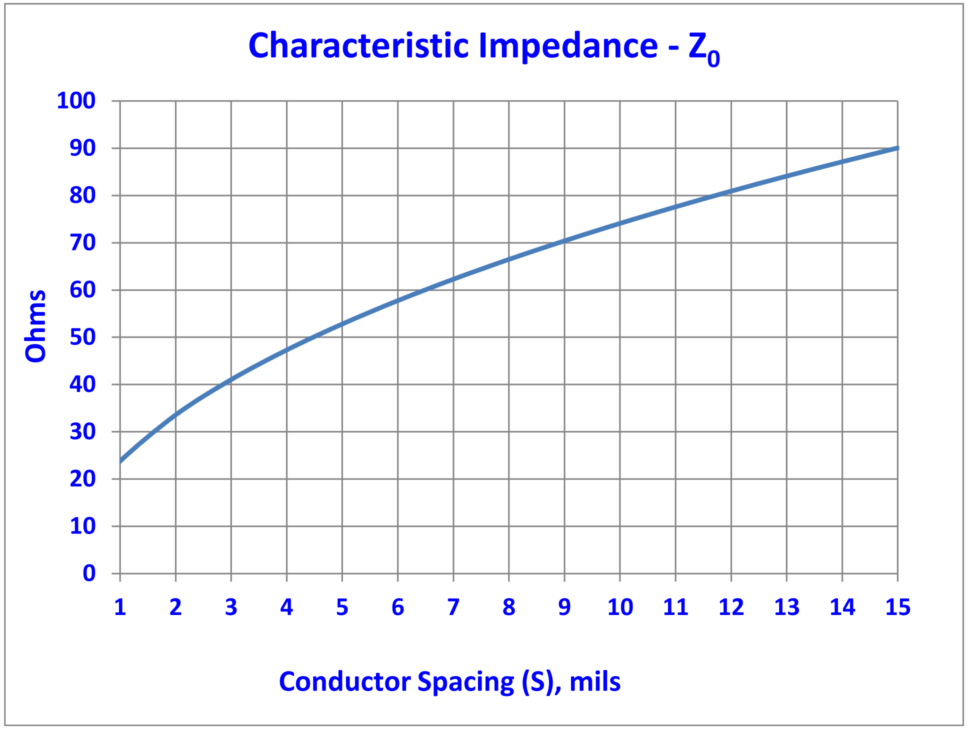
where

ϵ_r is the relative permittivity of the medium

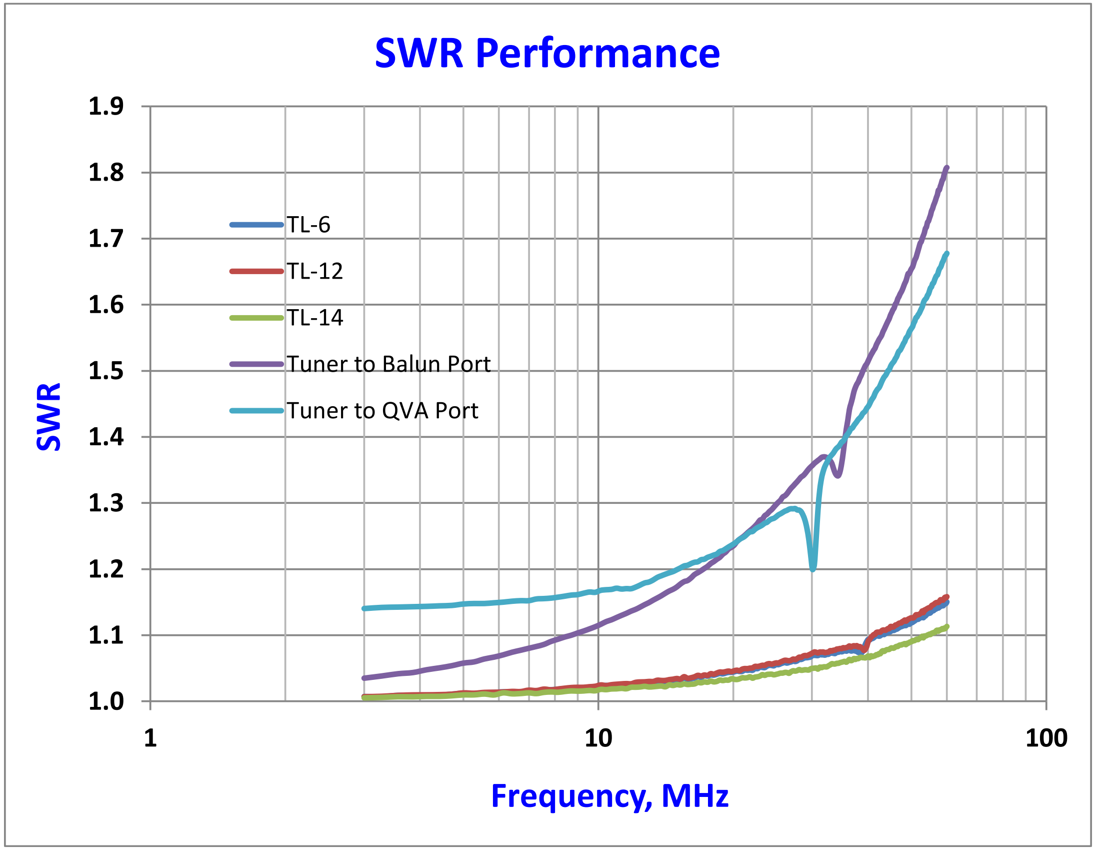
D is the center-to-center spacing of the conductors

a is the conductor radius.





Transmission Line Performance



- Tuner to balun port = TL6 +TL14
- Tuner to QVA port = TL6 + TL12

- Achieving a 50 ohm line with reasonable SWR up to 60 MHz was a challenge, requiring several attempts using various materials and spacing
- The best results were achieved with S=0, when the lines were “straight”
- The impedances change significantly when they were bent and twisted in order to solder them to their respective terminals

Wireless Relay Antenna Support

- A 9” x 1” x 1/8” Plexiglas L-bracket provides support for the AGT antenna
- The antenna wire was stiffened with a length of 2mm fishing line and the combination secured with heat shrink tubing
- The antenna wire/fishing line pair was tie-wrapped to the L-bracket which was hot glued to the top of the enclosure

Switch Box- Front View

Operational May 2017

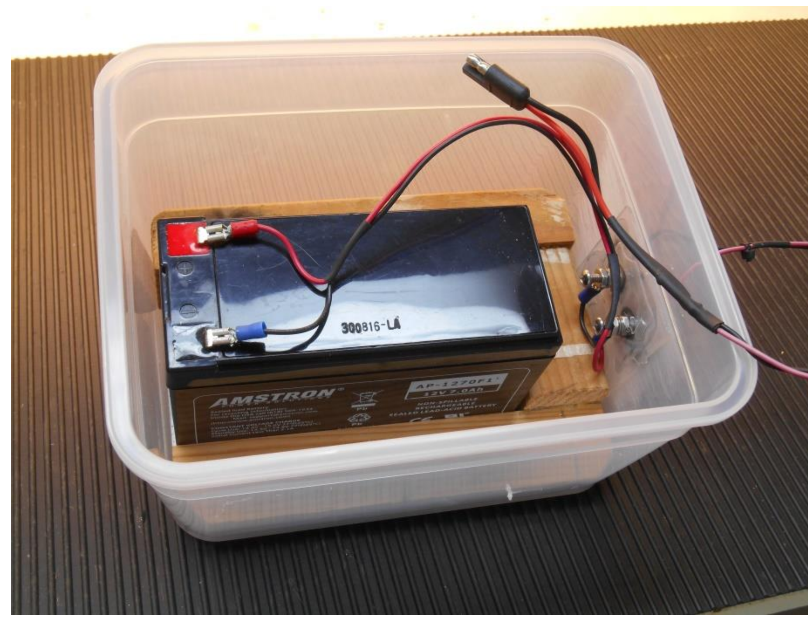
Clockwise from the top left:

- ❑ 1:4 Guanella balun
- ❑ Switch box
- ❑ Remote antenna tuner
- ❑ All components were mounted to a Polypropylene cutting board,
16” x 16” x .375”

Switch Box- Rear View

- The green external display indicates which channels are active

- On the backside of the cutting board, two parallel 1”dia PVC tubes, spaced 3” apart were screwed to the panel to form a cradle which allowed the assemble to be securely mounted to a tree with tie-wraps



- 12 volt 7 Ah SLA battery housed in a Snapware 16 cup, 9.15”x7.35”x5.28” food enclosure

Power Handling Capabilities

- **Requirement**: Operate at full legal power on SSB (50% operator duty cycle)

- **Approach**: Establish the power capability by ensuring that the voltage and current limits of various components are not exceeded, for a matched (R_L = 50) and miss-matched load (R_L = 1000, SWR = 20:1)

- **Component Limits**

  - AWG # 16 Formvar wire

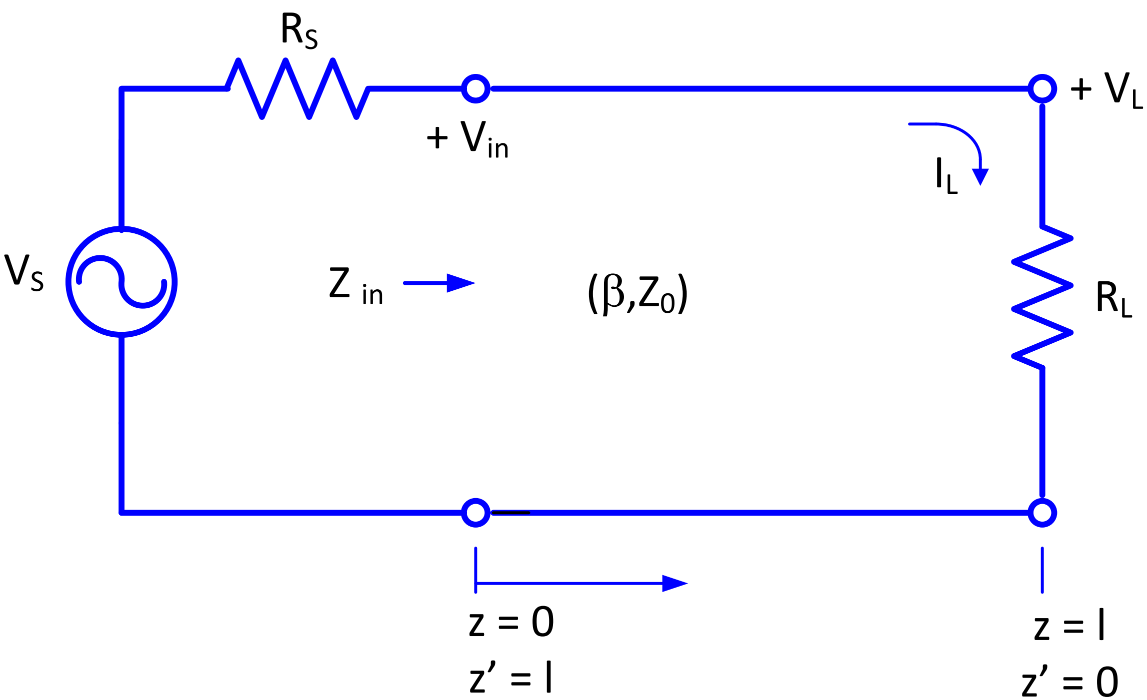
    - Breakdown voltage is 11,300 volts (**Ref. #3**)
    - 3.7 amps, de-rated to 1.85 amps (two wired in close proximity)

  - Power Relays

    - 3535 volts peak, pole-to-pole
    - 15 amp contact rating

Ref. #3: ssex Formvar, Magnetic Wire/Winging Wire, Product Data Sheet, https://essexwire.com/sites/essexwire.com/files/2017-08/Essex-Wire-Datasheet-Formvar-EN.pdf

Lossless Transmission Line Model



$$V(z') = \frac{V_s Z_0}{R_s + Z_0} e^{-j\beta l}\left(1 + \Gamma e^{-j2\beta z'}\right)$$

$$I(z') = \frac{V_s}{R_s + Z_0} e^{-j\beta l}\left(1 - \Gamma e^{-j2\beta z'}\right)$$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}, \qquad SWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

$\beta = \frac{2\pi f}{cV_f}$ = Phase Constant

ι = 9" = .229 meters

$$Z_{in} = Z_0 \frac{Z_L + j\, Z_0 \tan \beta l}{Z_0 + Z_L \tan \beta l}$$

- At the load, $z' = 0$
  - $V_L = \frac{V_s Z_0}{R_s + Z_0} e^{-j\beta l}(1 + \Gamma),\ volts\ peak$ $\quad Eq.1$
  - $I_L = \frac{V_s}{R_s + Z_0} e^{-j\beta l}(1 - \Gamma),\ amps\ peak$ $\quad Eq.2$
  - $P_L = \frac{1}{2}\Re e\left\{V_L I_L^{\ *}\right\} = \frac{|V_S|^2 Z_0}{2(R_s + Z_0)^2}\ ,\ watts$ $\quad Eq.3$

Power Handling for a Matched Load

- $R_L = Z_0 = 50, ohms$
- $\Gamma = 0,\ SWR = 1.0:1$
- For P_L = 1500 watts on SSB (50% operator duty cycle)
  - $V_S = \sqrt{\frac{2\times 10^4}{50} P_L} = \sqrt{400 \times 1500} = 774.5\ volt\ peak,$ $from\ Eq.3$
  - $V_L = V_S/2 = \mathbf{387.2\ volts\ peak},$ $from\ Eq.1$
  - $I_{L,\,SSB} = .2 \times .5(774.5/100) = 0.775\ amps\ peak = 0.548\ amps\ rms,$ $from\ Eq.2$
- $I_{L,\,CW} = .4 \times .5(774.5/100) = 1.549\ amps\ peak = 1.096\ amps\ rms$
- $I_{L,all\ other\ modes} = 1.0 \times .5(774.5/100) = 3.87\ amps\ peak = \mathbf{2.74\ amps\ rms}$
- Max power for modes with 100% duty cycles, limited by **1.85 amps rms** is
  - $P_{L,\,max} = \left(\frac{I_{L,max}}{.5}\right)^2 R_L = 50 \times \left(\frac{1.85}{.5}\right)^2 = 685\ watts$

Power Handling for a Miss-matched Load

- $R_L > 50\ ohms, V_{L,\,max}\ and\ I_{L,\,min}$ occur at the load
  - $R_L = 1000, ohms, \quad \Gamma = 0.9, \quad SWR = 20:1$
- For P_L = 1500 watts on SSB (50% operator duty cycle)
  - From Eq. 1:
    - $V_L = \frac{774.5\times 50}{100} e^{-j\beta l}[1+.9] = 737.4 e^{-j\beta l}$
    - $|V_L| = \mathbf{737.4\ \ volts\ peak}$
  - Applying the duty cycles to Eq.2:
    - $I_{L,\,SSB} = .2 \times .5 \left\{\frac{774.5}{100}[1-.9]e^{-j\beta l}\right\} = 0.0737 e^{-j\beta l}$
    - $|I_{L,\,SSB}| = 0.0737\ amps\ peak, \ = \ 0.052\ amps\ rms$
- $|I_{L,\,CW}| \ = \ 0.104\ amps\ rms$

Power Handling Conclusions

- Power Handling Capability
  - $P_{L,SSB} = 1500\ watts$
  - $P_{L,CW} = 1500\ watts$
  - $P_{L,All\ other\ modes} = 685\ watts$
- All voltage and currents for the above power limits are well within component limits for matched and mismatched (SWR= 20:1) loads

Antenna Selection Display

- Requirements
- Design
- Construction

Antenna Selection Display

- **Requirements**
  - Indicate which antenna of the three antennas was selected
  - Indicate when both Channel A and B are active
    - If both channels are active, only the QVA is connected to the Shack while RE-1 is connected to antenna-2 drawing unnecessary battery current
    - Knowing that both channels are active, I can deactivate Channel A and increase the time between battery charging cycles
- **Design**
  - Use a second WR-02 in the Display to indicate which antenna was selected
  - The second WR-02 was reprogrammed so that both wireless relays, one in the Switch Box and another in the Antenna Display, produce the same response from one set of controllers

Antenna Display Design (Continued)

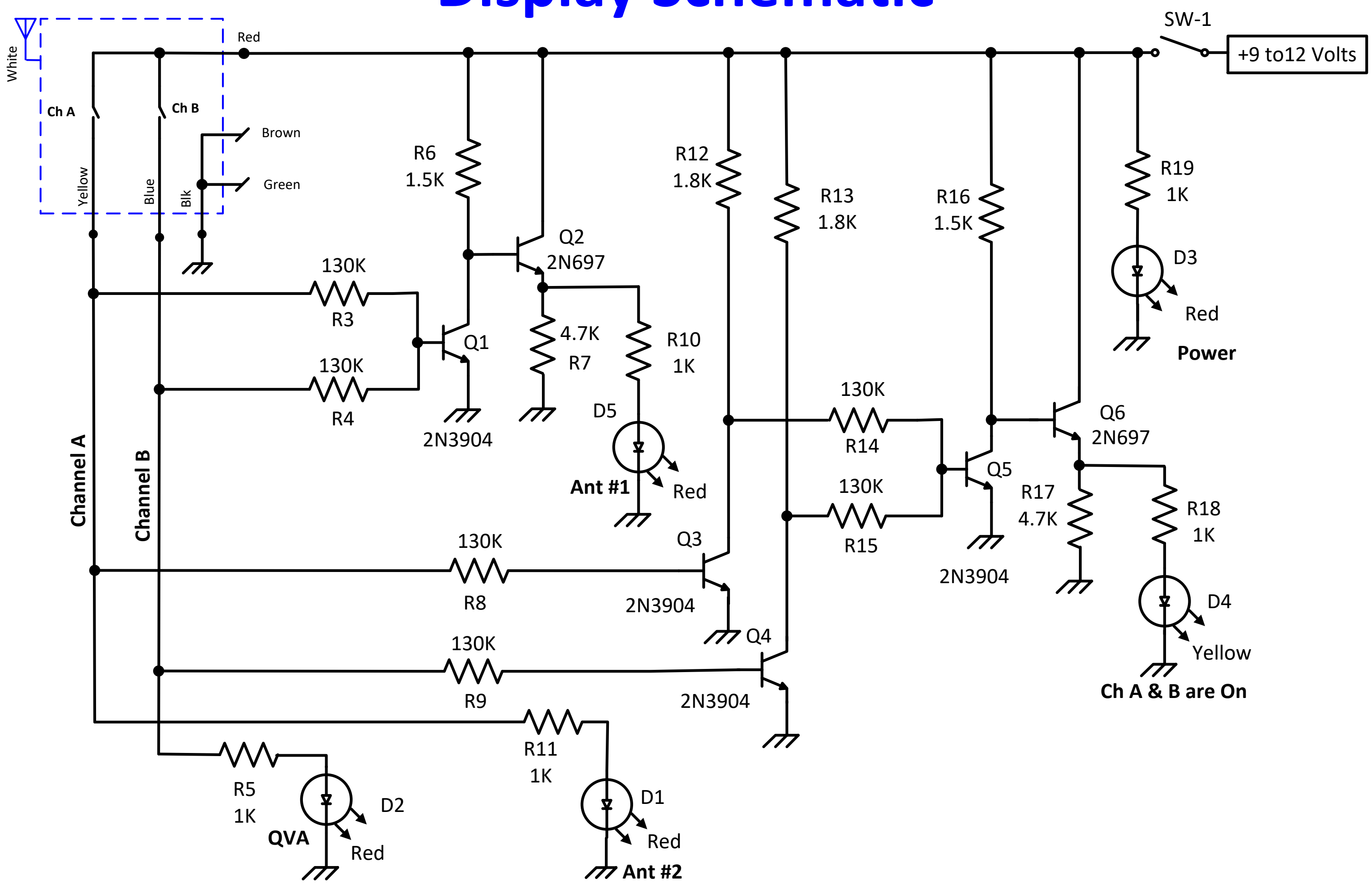
- The Requirements were translated into a Truth Table for implementation

Display Truth Table					
Inputs		Outputs			
Ch. A	Ch. B	Ant #1	Ant #2	QVA	Both On
0	0	1	0	0	0
0	1	0	0	1	0
1	0	0	1	0	0
1	1	0	1	1	1

- From the Truth Table four Boolean equations were generated, one for each output

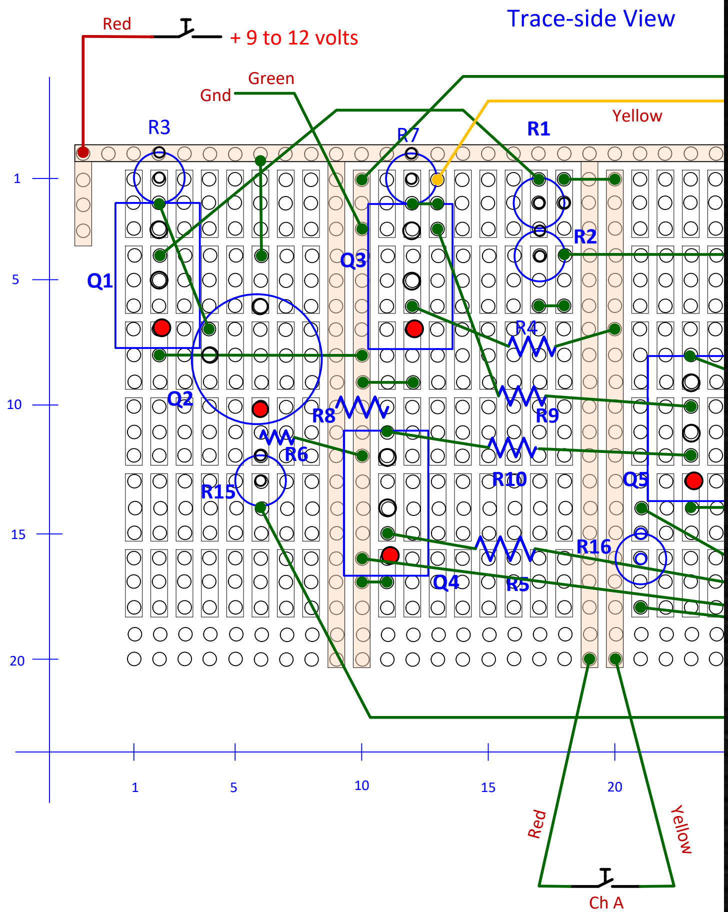
$$Ant\ \#1 = A' \& B' = (A + B)'$$
$$Ant\ \#2 = A \& B' + A \& B = A \&(B' + B) = A \& 1 = A$$
$$QVA = (A' \& B) + (A \& B) = B \& (A' \& A) = B$$
$$Both\ On = A \& B = (A' + B')'$$

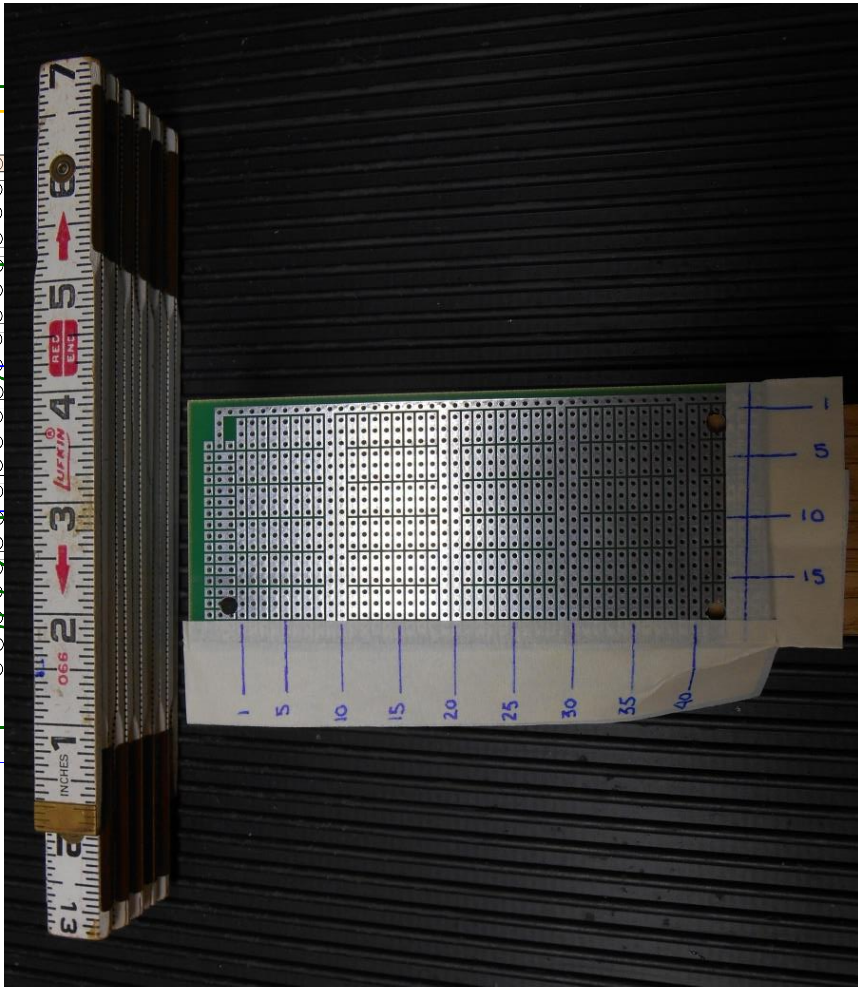
Display Schematic



- Boolean equations implemented in Resistor-Transistor Logic (RTL)
- Q1 and Q5 are NOR circuits
- Q3 and Q4 are Inverter circuits
- Q2 and Q6 are emitter followers
- A 9 volt wall wort powers the display

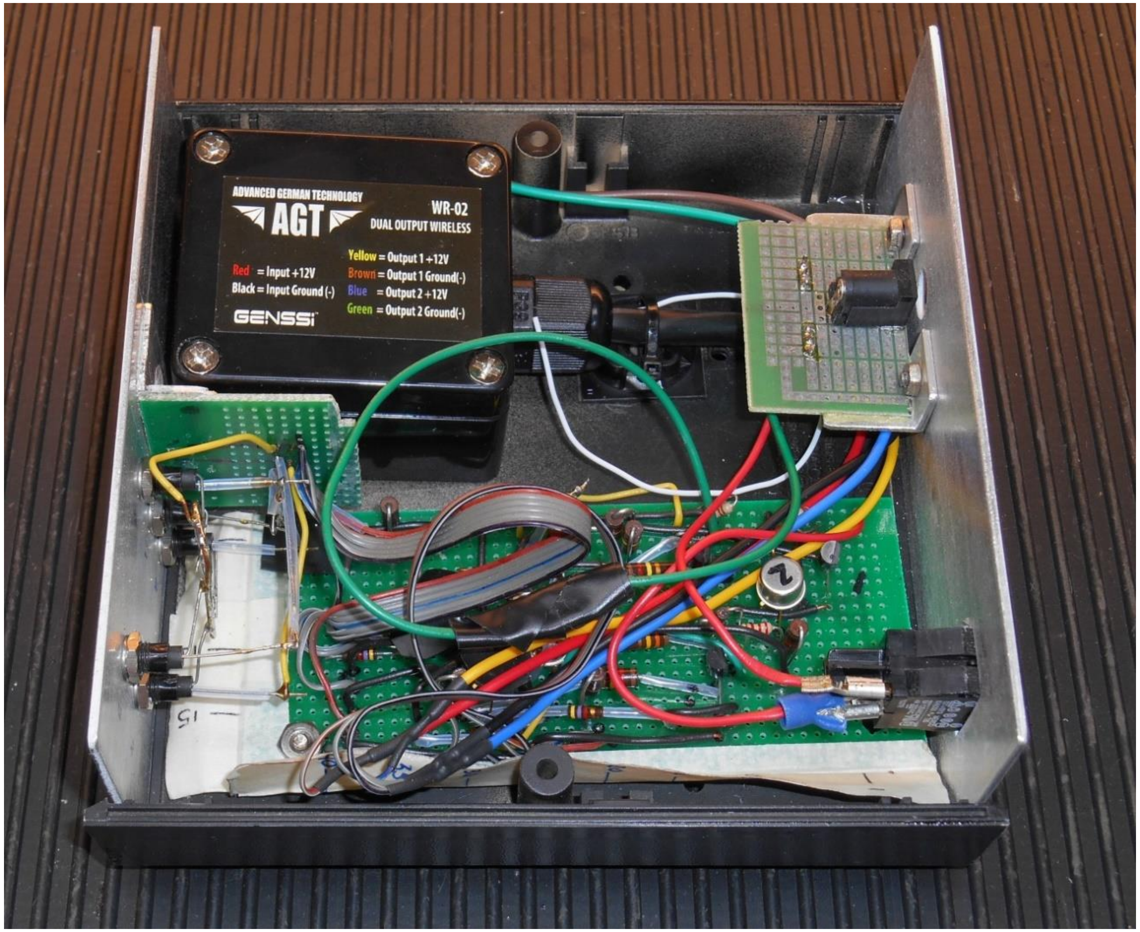
Display PCB





- A 2” x 5” Velleman 3-hole Island Eurocard PCB was used to wire the display
- The 3-hole island pattern was replicated and virtually wired in Microsoft Visio

Display Construction



- The enclosure is a repurposed 5"x 2.5" x 6" project box
- The rear panel (right) contains
  - Wall wort connector
  - Power switch
- The front panel (left) contains
  - LED indicating power
  - 3 LEDs indicating antenna selection

Reprogramming the Second WR-02

- ❑ Hold down the pushbutton until the LED lights
- ❑ Select one of the “remote controls” for the Switch Box, hold button A for a few seconds
- ❑ Verify that this control activates both Ch A and Ch B
- ❑ Select the **other** remote control for the Switch Box, and repeat the above process only this time, hold button B for a few seconds
- ❑ Again verify that the second control activates both channels

Front & Rear Panel Graphics

- The front and rear panel graphics were generated in Microsoft Visio
- The *mirror image* of the graphics was printed onto an ultra-thin plastic transparency
- After cutting out the graphics, the "ink" side of each was glued to the respective panel using 3M Super 77 Multipurpose (spray) Adhesive
- This produces a scratch resistance display

Conclusions

Antenna display unit sitting atop my Kenwood TS-590s

The wireless switch-box has been a major addition to my shack allowing me to rapidly switch between antennas during contests or while chasing DX-all from the comfort of my shack.

Questions ?

Comments ?