An Antenna Switch for the KiwiSDR

I have recently designed and built an antenna switch for use with the KiwiSDR and its antenna switch extension. I took on this project because I wanted a convenient way to compare results from a variety of antennas, particularly several different broadband active antennas I've been developing, both at my home location as well as for a remote site I use for some of these comparisons. This note describes my progress as of March 2019. I'm offering it in the event that it may be of interest and provide help to others who might have similar uses.

In recent years I have been using WSPR as a tool for both examining propagation mechanisms, as it was originally intended, and also for examining amateur radio station performance and better understanding antennas. Although I have been transmitting on WSPR from LF through the 23 cm amateur band as part of these studies, I've become interested in the problem of minimizing receive system noise floor. I've been desiring to reach as close as I could to the propagated noise floor on every amateur band since it is this floor that sets the ultimate limit for receive sensitivity. These efforts have led me to believe that the vast majority of amateur stations, certainly those below the UHF bands, are not operating down to this limit.

WSPR has been a very useful tool for examining noise since there is a large base of sites continuously reporting signal/noise ratio (SNR) from a large number of representative amateur stations worldwide, together generating a large amount of data which can be analyzed. Examination of the parity among stations which both transmit and receive on the WSPR network have led to new insights. Some special spots, such as those from very high altitude WSPR-equipped balloon transmitters have enabled what are effectively far-field antenna range measurements of stations and noise floors.

When I discovered the excellent work that John Seamons and others have done in the KiwiSDR project I was almost immediately attracted to it and quickly discovered the usefulness of the KiwiSDR as a tool for measuring and better understanding noise at amateur stations as well as antennas and propagation in general. In particular, the spectrum analysis capability of this receiver, available data in real time from a large number of receivers operating worldwide allowed additional insight into station performance, noise and its limitations. As I spent a considerable part of my working career designing and producing spectrum analyzers this capability of the KiwiSDR particularly attracted me to it as a platform.

While studying noise and ways to achieve low noise floors in the amateur bands I've been interested not only in the instrumentation but also in the antennas used as "probes" used to measure it. The KiwiSDR encouraged me to seek an effective broadband antenna, one that could work well from VLF through HF, as a tool. A prototype design of a small symmetric active antenna I first tried, a dipole, was constructed and used. Bob Dildine,,W6SFH, (SK) wrote an article describing that prototype in September 2017 QST. Since then I have built a number of different antennas and preamplifiers, both active electric dipole and magnetic loop designs as well as more traditional antennas passive antennas such as dipoles and monopoles.

In studying noise sources and in particular the coupling of these sources to the KiwiSDR I've come to realize that one of the dominant coupling mechanisms of signals that degrade receiver noise floor is via common-mode signals. These can exist almost everywhere in the system; they exist on the antenna itself, within ground systems, on the feedline and other connections to the antenna and through the KiwiSDR itself. I'm presently of the opinion that for most amateur stations and even most KiwiSDRs that the dominant source of unnecessary SNR degradation, QRN and QRM, is due to common mode currents. Near-field coupling to a variety of types of local sources, interference which is attenuated as a function of distance faster than the inverse-square field of a radiated plane wave emanating from a distant source dominates a majority of amateur stations.

Although resignation to the existence of "all those noisy digital devices" and the mindset that interference has to be accepted seems to be the prevalent wisdom within the hobby, I've found that this is not the case. I have come to believe that the vast majority of amateur receive systems are not limited by either propagated noise, which would be the desired condition, or by radiated noise from local interferers, as is commonly espoused, but by coupling to near-field sources and in particular common mode noise. Designing and building an Antenna Switch for the KiwiSDR has been a part of studying these sources, building better antennas and extending my effort to create a broadband LF-HF receive system - one limited by propagated noise.

How Good Does an Antenna Switch Need to Be?

In using and measuring the KiwiSDR I found it to have fairly good performance in general, including rather good power supply rejection ratio (PSRR). Even a large noise and signal superimposed on the PS input of the KiwiSDR, for example a .2 V peak-peak at 160 kHz from a 12V-to-5V buck converter, results in relatively small amounts of QRM at the fundamental and its harmonics. This amounts to on the order of 60 dB or more PSRR for the receiving system. But I also found that common mode current from a well-isolated source, injected on a line or lines at the PS, LAN end of a KiwiSDR enclosed in its metal case and having a return path through the "ground" at the SMA end of the receiver reveals on the order of only 70 dB rejection. An isolated 0 dBm 50 ohm source produces around an -73dBm/S9 signal within the KiwiSDR even though that current flows only through "grounds". It appears that current paths through the PCB metalization are such that IR drop generates signal that appears as an input to the KiwiSDR's preamplifier.

Knowing this limitation, when I started designing an antenna switch I knew from the beginning that it would have to be an isolating switch. It is necessary to reduce common mode currents if the result was not to degrade the noise floor and sensitivity of the receive system. Since the KiwiSDR has a native noise floor, due to the 24 bit resolution of the information channel, of about -157 dBm/(1 Hz) this isolation would ideally allow no more than about the equivalent of a 80 dBm interfering signal generating CM current if WSPR signals were not to be compromised. Estimating and equating this isolation goal in the context of unknown source and load impedances for potential common modes coming in and going out of the KiwiSDR cables and lines is difficult. It's further aggravated by the uncertainty of coupled interference levels but since it isn't uncommon to see -20 dBm signals on these lines which can exhibit several hundred ohm impedance it would seem that 100 dB of isolation could be useful. Achieving this would imply a series impedance well above 1 Mohm - a few femtofarads at 30 MHz! It became obvious that complete elimination of CM current induced noise was more than I was going to be able achieve for an antenna switch operating over LF to HF but I decided to try to do my best at designing and constructing the best isolating antenna switch I could anyway. That process continues to this day.

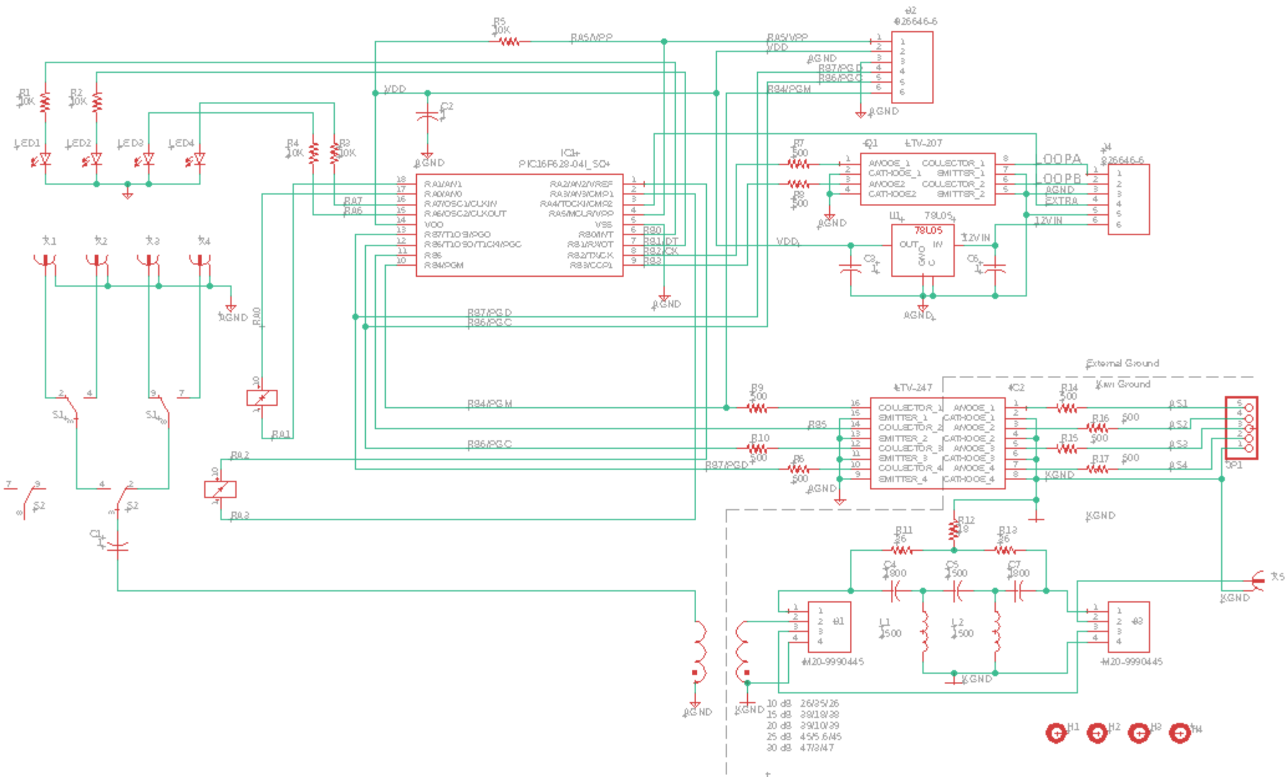
My original thought for the switch design and the way I configured the first version was to replace the aluminum end plate on the antenna end of the KiwiSDR enclosure with a PCB. That design provided complete separation of the KiwiSDR enclosure and SMA antenna shield (note that these are notequipotential, as described above) from the incoming antenna lines and grounds. Although I wanted the switch to work well over the entire KiwiSDR range, say 10 kHz to 30 MHz, I used a small SMD transformer having low inter-turn capacitance. Even lower coupling between windings and more isolation is possible with different transformers but I wanted to maintain good performance down to VLF and these transformers were not specified to operate at VLF.

The switch is controlled by information from the KiwiSDR Antenna Switch Extension and come from using the BeagleBones GPIO pins that have been made available as an option for the switch extension. This extension with the GPIO option was compiled into a running KiwiSDR and control function verified. Within the switch, I used opto-isolators with < 1 pf coupling to connect to the switch control circuitry. I used opto-isolators again to enable couple of control lines for use when the switch was selecting an LZ1AQ dipole/loop antenna system.

Since I was aware of the extreme requirements for isolation and sensitivity of the system yet wanted the flexibility of software configurability for both antenna switch and control lines, I decide to use a PIC controller but to arrange it to have it respond only to control line changes and for the CPU to run at a low clock speed and to "sleep" when not actively switching antennas. Along with the use of latching relays for switching I was able to eliminate any noise or signals that might otherwise be produced by the controller.

To optimize this switch for use with the KiwiSDR I included the provision for common-input attenuation and filtering. An ideal antenna switch needs to not only deliver the input from the antenna (ideally limited by propagated noise levels) but might also protect the KiwiSDR from signal levels that would exceed the approximately 14 dBm instantaneous input limit which would cause the ADC to exceed the top of its range. Hard limits, such as those that are provided by protection diodes or other limiting produce distortion which is very undesirable. While I've had good success with combinations of high-pass filters and attenuators, recently I've been using notches and band-stop filters to limit individual strong signals at particular frequencies while not degrading the sensitivity and noise figure over large bandwidths. Since this sort of pre-conditioning is largely locale dependent and since I wasn't sure I'd arrived at a the best solution, to make the switch widely usable I added the provision for a daughter-board which can contain environment-specific filtering circuits.

The following figure shows the schematic of the present version of the switch:



From the schematic it can be seen that there is no DC path between the KiwiSDR side and the antenna side of the switch. Only the coupling through the opto-isolator and the broad band isolation transformer and any through-the-air self capacitance coupling of the whole assembly offer a path for common mode currents.

Although the first version of this switch was designed as a replacement for the aluminum end plate on the antenna end of the KiwiSDR enclosure, because of the difficulty of eliminating any PCB-to-KiwiSDR coupling and in appreciation of the enclosure design, which John Seamons indicated took significant effort, in newer versions of the switch I have added the board on insulating stand-offs instead. Holes for the antenna input and GPS antenna cables were provided in the switch PCB. This arrangement provides flexibility and a maximum “hands-off” approach while keeping the combination receiver+switch contained to a small volume and cables short, further minimizing the opportunity for ingress of unwanted signals.

The current results are shown in the following photographs.

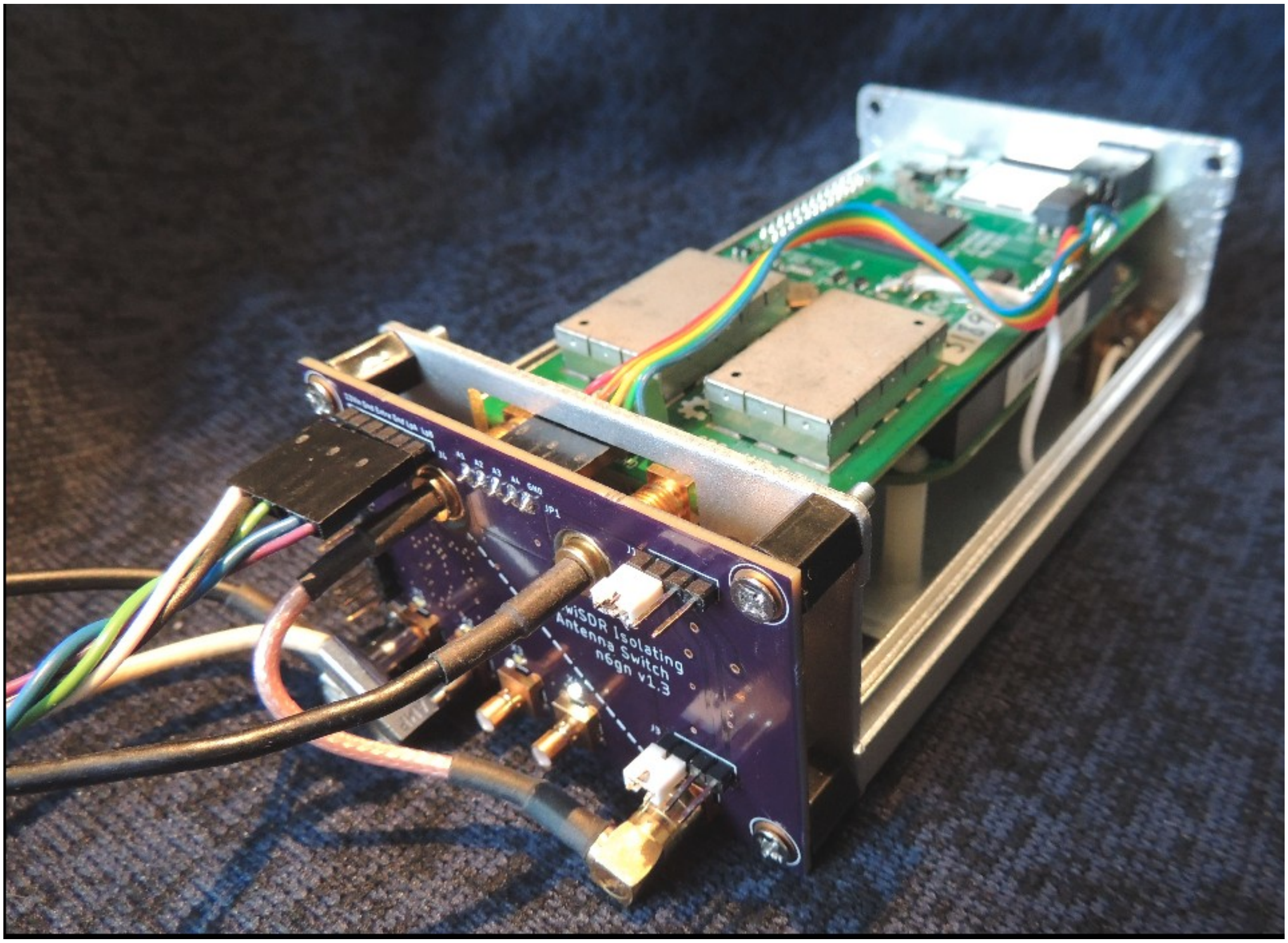


Illustration 1: Here is a photograph of a current version of the switch with the top cover of the enclosure removed so that the control lines and their connections are visible. Connector and lines for switch power and control lines for a LZ1AQ antenna system come away at the upper left of the switch PCB. Antenna inputs are along the bottom left with LED indicators showing which is active. The switched output is at the board's lower right and a short jumper cable connects this to the KiwiSDR antenna input SMA. White jumpers are in place on the two headers on the right side to select straight-through or on-board attenuator/filtering. These jumpers may be replaced by a small daughter board with location specific filtering circuits as described.

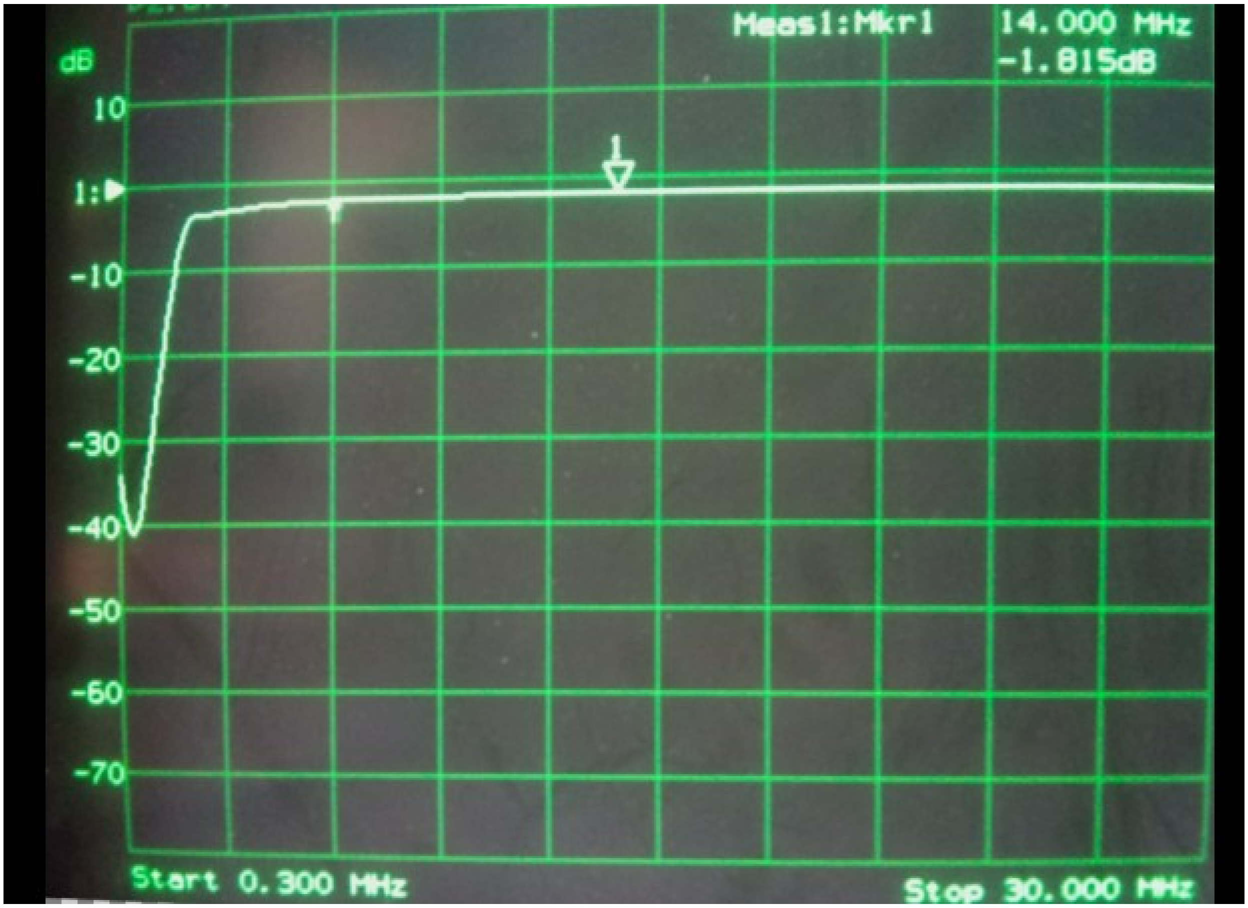


Illustration 2: This photograph shows a measurement from one antenna input to the switch output/KiwiSDR input with the HPF selected:

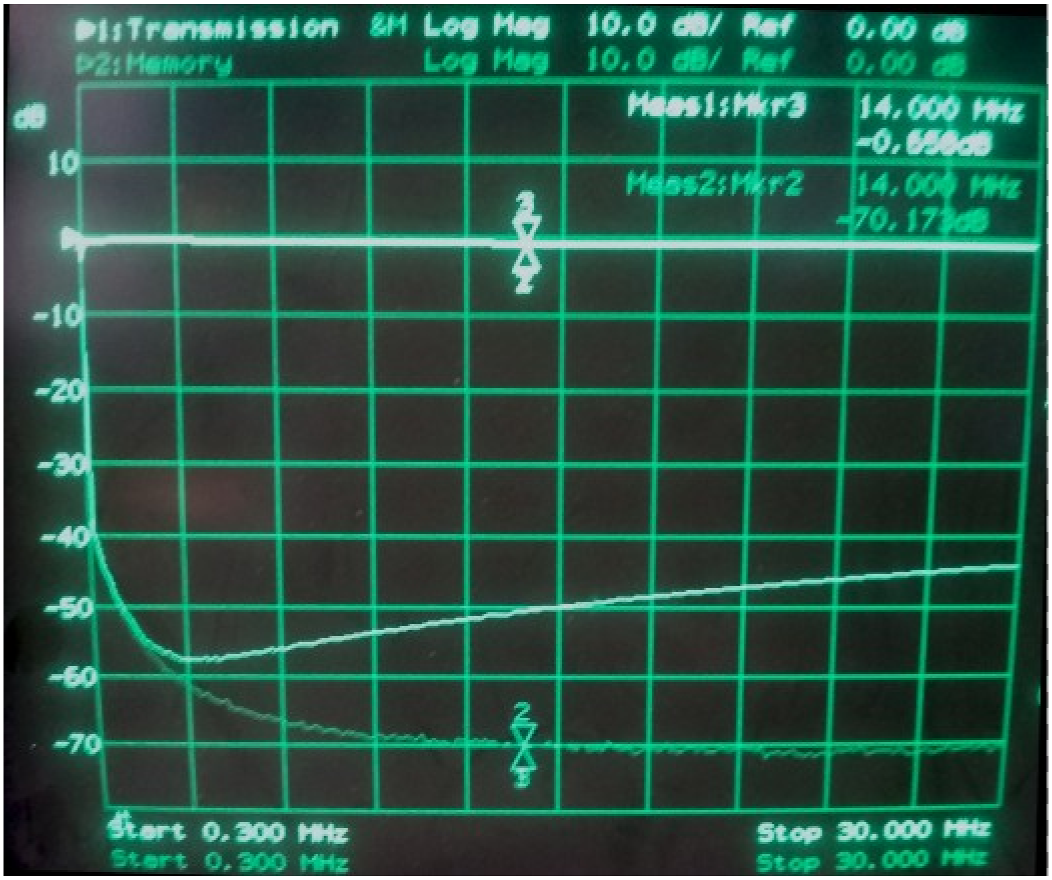


Illustration 3: This photograph shows a measurement of On/Off ratio of the switch for a connected and two combinations of deselected antennas

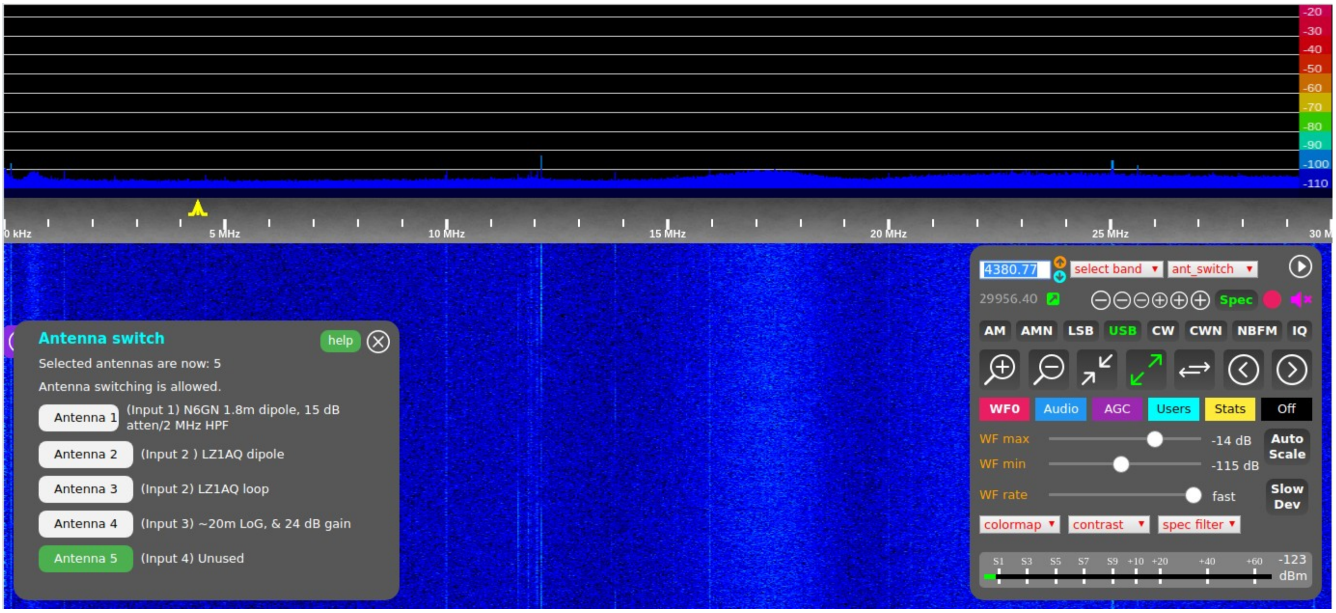


Illustration 4: As a sort of proof-of-performance, though not one that stresses the CM rejection capability of the switch, here is the broadband spectrum showing noise floor from a calibrated KiwiSDR outfitted with the switch while three de-selected antennas are connected:

What Next?

Like my other projects, this one never seems to be finished. I’ve used the switch for a while now and the current version seems about ready for deployment at a remote site but there still exist changes which I think could make it better.

I think a switch of this design may be useful to other KiwiSDR owners, however, I don’t personally have desire to manufacture and support such use. Other projects consume my interest and time but if someone is interested in themselves building one of these for their own use, please contact me for the present schematics, PCB layout (Eagle PCB software format) and Microchip PIC code for compilation.

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