The W1GAN 2m Homemade Duplexer re-visited

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This original design has been around for over 40 years now and while it is still one of the simplest and most economical ways of home-brewing a VHF duplexer, there are a number of improvements that can be readily implemented to improve its overall performance and serviceability.

Our radio club built one of these duplexers for our 2m repeater in the late 70s and it provided many, many years of reliable service. Recently, we had an opportunity to significantly improve the installation with the addition of a Telewave 1486 duplexer. That provided an opportunity to revisit the W1GAN design with a view to refurbishing it for redeployment to another project.

Mechanical Considerations

One of the problems experienced with the original execution of this duplexer design is that the builders did not provide adequate mechanical support of the tuning rod lock-nut.

The original design showed a bushing from under the lock-nut to the top flange of the cavity which would transfer the locking force directly to the flange. This provided a stable way of locking the rod in place. Unfortunately, when our duplexer was built, this spacer was omitted and the lock-nut loaded the top of the diecast box when it was tightened down. The mechanical stress on the box lid flexed it sufficiently to introduce some variance when the nut was tightened which made the cavities difficult to align precisely. Suitable spacers were made and implemented using thick-walled stainless steel tubing. The load from the lock-nut is now transferred directly onto the top of the flange making the cavities much more stable mechanically.

The original W1GAN design did not provide any guidance for mounting the duplexer. The actual physical disposition was left to the imagination of the builder and our installation was basically a wooden rack which sat on the floor. In practice, rigid mounting of the cavities with adequate mechanical support will contribute greatly to the long-term stability and viability of such a device, especially if you have enough room to rack-mount it and keep it out of harm’s way.

Suitable mounting straps that clamped the cavities onto rigid frame members were fabricated to replicate designs that are used on modern commercially made duplexers. This offered the opportunity to design a mounting system that would permit rack mounting inside a cabinet where the duplexer would remain out of harm’s way and would provide adequate support for any interconnect cabling.

Connectors

One of the limitations of the original design was the use of BNC connectors. The BNC connector has limitations which stem from its physical design. Principal amongst these is the fact that the connectors rely on a spring bayonet action to locate and seal properly. The mechanical properties of these connectors can be compromised over time and reduce their effectiveness as oxidation and wear accumulate. Corrosion is also likely to increase the potential for noise and intermodulation products in high-RF environments such as are likely to occur on group communications sites.

A better option is to use N series connectors which provide a much more stable platform. The positive threaded body allows for a much firmer and more stable mechanical action and the internal rubber seal provides for at least some protection against the assault from air-borne moisture likely to be encountered on remote sites.

It is important to note that the connector internals form part of the RF path and will consequently contribute some amount of phase rotation as the signal propagates along that path. The path length of the male/female BNC connector combination is different to the N series and will therefore need to be taken into account when calculating the length of the interconnect cables. You will also need to correct the cable length if using 90 degree connectors as I did in this case. The choice of 90 degree connectors was made for three reasons. Firstly, they're more compact and allow for tighter packaging of the final product. Secondly, the overall signal path length can be easily measured centre to centre. Thirdly, if you have a ready source of the crimp barrels, they're re-usable which greatly facilitates the building of interconnect cables as some trial and error may be necessary.

Interconnect Cables

There is nothing wrong with the original RG-223 cable used in the design as it's adequate for the task however the availability of modern mechanically equivalent cable types that are compatible with many commonly available N series connectors has opened up the list of choices significantly.

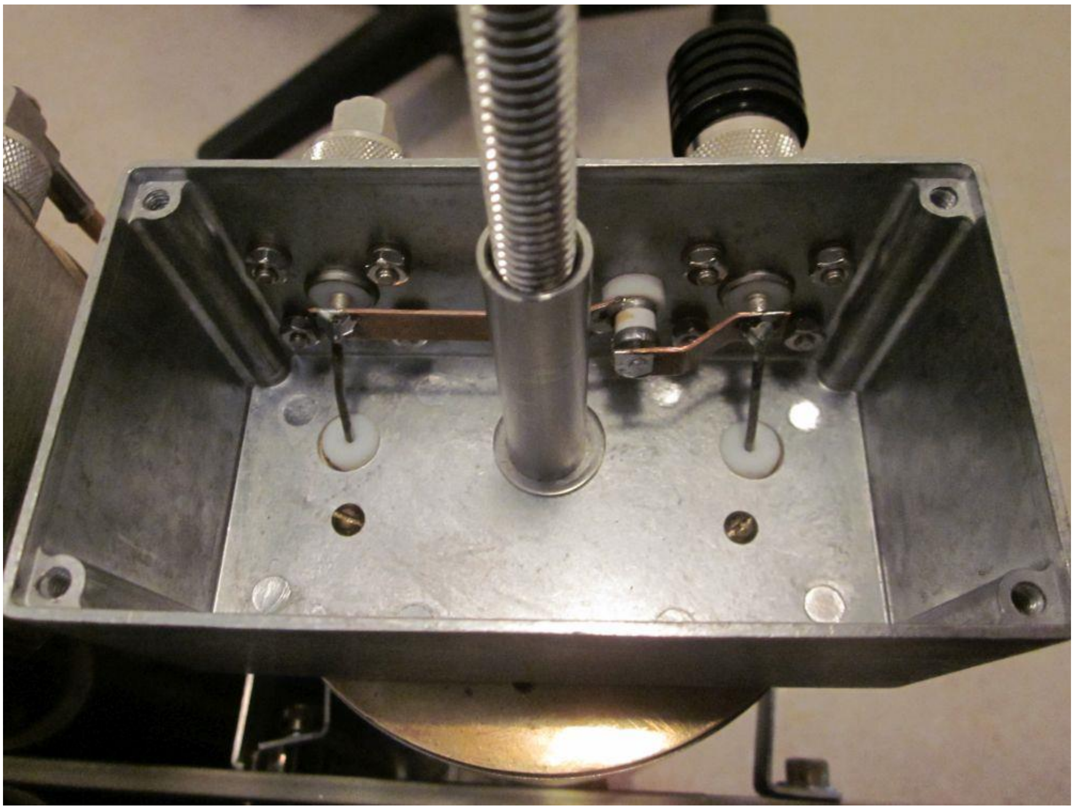
One of the more readily available types of cable is RG-142. Its loss characteristics at 2m are not significantly different to RG-223 or not enough to matter in any case and suppliers of compatible N series connectors are plentiful. RG-142 was chosen for this project simply for these reasons.

One consideration when changing the coax cables is that you WILL need to correct for the velocity factor of the cable if you change cable types. RG-223 uses a polyethylene dielectric (VF = 0.659) while RG-142 employs PTFE (Teflon) as the dielectric (VF = 0.694). The two cable types have different velocity factors. In this case, it was simply a matter of scaling the dimensions proportionally taking into account the ratio between the original and the new velocity factors and applying the correction to the cable lengths. A correction for the N series connector path was also included in the calculation. In practice, you will need to take all of these factors into account for your specific circumstances.

The method I used was to calculate the phase rotation produced by the original cable lengths then normalise this value to the free space wavelength of the centre frequency of the duplexer, and recalculate the same amount of phase rotation for RG-142 coax using its velocity factor then factoring in the difference in the connector dimensions to the overall length of each cable. The overall cable length was calculated at 7.4 inches centre to centre on the 90 degree N series connectors. Like I said though, this will be specific to the cable and connectors used so it is important that the cables are calculated for individual circumstances.

Shunt Trimmer Capacitors

A stable trimmer capacitor with a relatively low value at minimum is essential for correct tuning. While the original air-spaced capacitors were fine, it was considered that the mechanical arrangement for supporting them on the original design could be significantly improved with some care. A suitable way of rigidly mounting the trimmer capacitors that was stable and maintained good earth isolation was devised using spacers made of PTFE rod. The trimmer capacitors used are Johanson 5202 trimmer capacitors. The capacitors have a range of 0.8 to 10pf which should be adequate however the range can be modified simply by connecting a low value ATC porcelain capacitor in parallel if required.

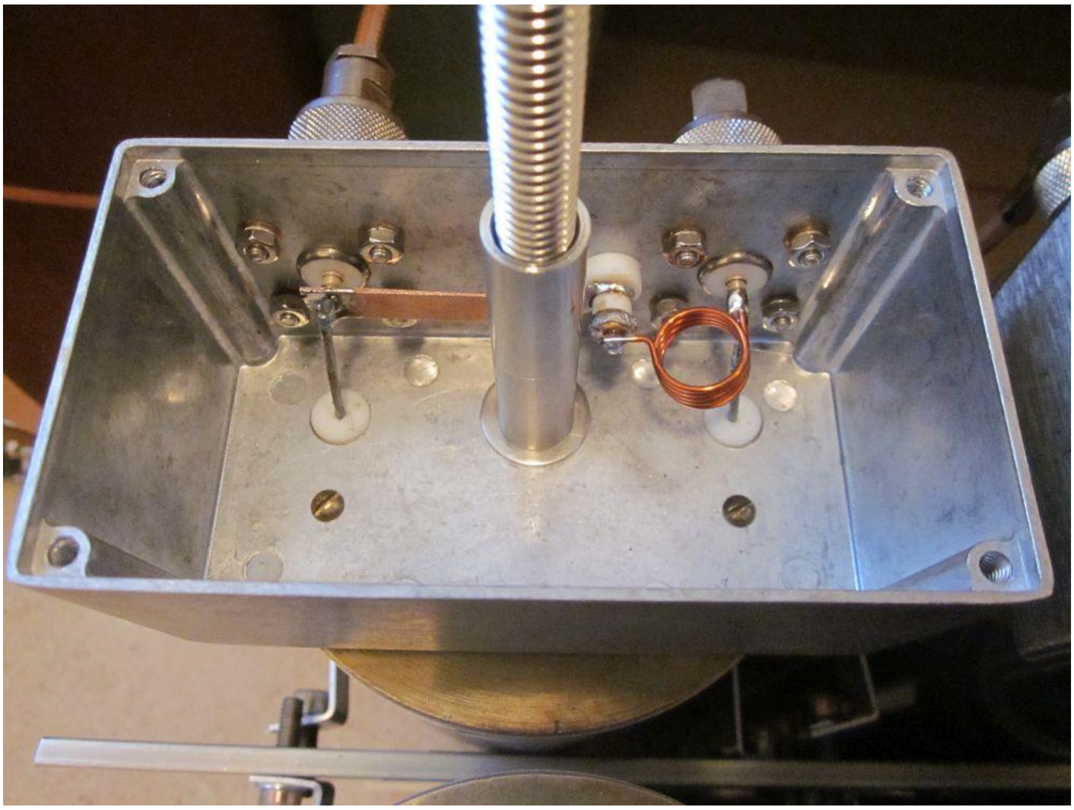


Low-side notch cavity showing location of Johanson 5202 trimmer capacitor on PTFE insulated bushing

Shunt Inductors

One of the main problems with the original design is that the notches created by the shunt inductances were difficult to align. The inductors used were very low in value and mechanically difficult to vary. If the notches didn't line up between all the cavities, then it meant pulling everything apart again and starting over.

A simple remedy was to introduce a series LC shunt using a trimmer capacitor with more inductance than is required and making the notches adjustable (with due acknowledgement to Jaques Audet, VE2AZX for this idea). Four turns of 14 gauge enamelled wire, close spaced on a half inch former in series with the same Johanson 5202 capacitors used on the low-notch cavities was sufficient for the notches to tune correctly but it may pay to experiment in specific cases if the tuning range doesn't meet your needs.



High-side notch cavity showing location of inductor and Johanson 5202 trimmer capacitor on PTFE insulated bushing

Internal Strapping

It is important to keep the inductance of the links that connect the shunt Ls and Cs as low as possible. The original design used copper strap and there is no reason to change this approach. Solid copper straps are mechanically stable, easy to achieve and provide a strong method of mounting the necessary components.

Tuning and Setting Up

The tuning procedure is exactly as described in the original article. Cavity bandpass is adjusted on each individual cavity first. The respective individual high side/low side notches are done next then the whole thing is assembled and checked again with any final ‘fine’ adjustments completed at this stage.

It helps if you have access to a Vector Network Analyser (VNA) or a spectrum analyser with a tracking generator.

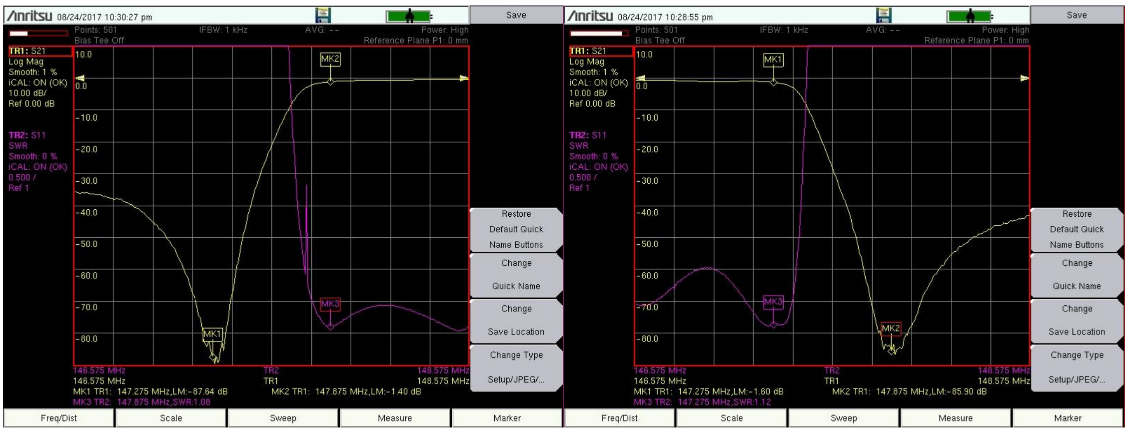
One point worth noting is that ANY mechanical stress applied to the cavities will detune them to some extent. Final adjustment should only ever be completed once the duplexer is *in situ* at its final location and all fasteners are firmly tightened down.

The W1GAN duplexer nearing completion after refurbishment showing 19" rack-mount frame and lugs

Performance

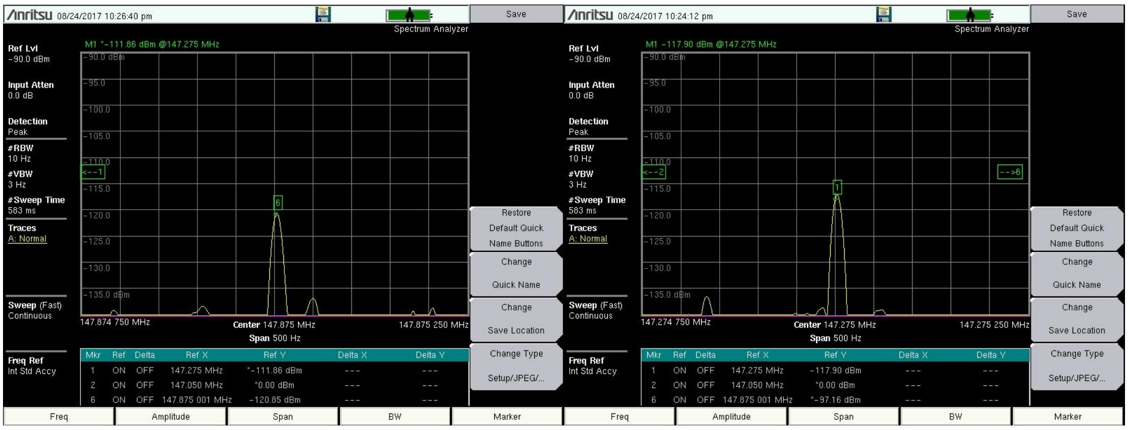
The set-up in this case was for a 2m repeater with a transmit frequency of 147.275MHz and a receive frequency of 147.875MHz. It is important to note that there was nothing wrong with the duplexer before it was refurbished. It was working and doing so reliably and meeting all the original design specifications. The only reasons it was refurbished was to allow for an update in design philosophy, permit rack-mounting for another project and hopefully extend its life for another 30 years!

Nothing else in the original design was changed. All original dimensions were retained including those for the coupling loops and spacing save for the excess length being cut from the tuning rods. We were never likely to run the thing at 120MHz anyway so it was not necessary for it to tune that low!



VNA screen grabs showing RX and TX bandpass insertion loss, some IL was sacrificed in lieu of a VSWR

The insertion loss for the completed rebuild was 1.40dB down the RX side and 1.60dB on the TX side. The VNA was noise limited at the reject notches and these were measured separately using a +5dBm signal source and spectrum analyser. This technique allows you to reduce the span and bandwidth thus reducing noise and producing a much more stable pattern to tune out the notches with.



Spectrum analyser screen grabs showing measured levels at each rejection notch for a +5dBm input signal

The signal generator was set up at the desired reject frequency in each case and the output signal level calibrated to the spectrum analyser for +5dBm for each measurement. The spectrum analyser was connected on the antenna port and the signal source applied to each of the RX and TX ports in turn with the opposing port terminated into a 50Ω load. The resulting screen grabs show a level of -120.86dBm at 147.875MHz and -117.90dBm at 147.275MHz respectively for a +5dBm input level.


The completed duplexer in its final installation

Acknowledgements
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