10 GHz Preamp

Simple and Cheap

Paul Wade W1GHZ and Tom Williams WA1MBA ©2025
w1ghz@arrl.net & tomw@wa1mba.org

The Simple and Cheap 10 GHz transverter has proven popular and has gotten some hams started on 10 GHz. Most of them quickly find that a bit more power would make contacts easier, and improving the receive noise figure would hear better. I (W1GHZ) have not found a good, cheap solution to higher power, but modest power amplifiers show up in surplus, and higher power ones are available.

Our goal is a preamp that will considerably improve the 10 GHz transverter, that can be built by anyone who can build the transverter, and cost around $10.

Good Low Noise Amplifiers (LNA), often referred to as preamps by hams, are available, but at a cost of more than the whole transverter. I looked for low-noise MMICs, but found that they start around $40, and consider 2 dB NF as low noise, and come in tiny packages unsuitable for hand assembly. While working on some lower frequency LNAs[1], I stumbled across a promising part at Mouser.com, the CE3512K2, rated at 0.3 dB NF at 12 GHz at a price under $3. I looked at the S-parameters and noise parameters, and then designed some PC boards that might work, using ordinary FR-4 type material for low cost. I used the thinnest readily available boards, 0.6mm thick. The first test board, with 50Ω lines, had a noise figure a bit under 2 dB – quite promising.

With some snowflaking, tuning, and two rounds of prototype boards, we came up with LNA designs with good noise figure. The boards seem quite repeatable, with noise figure around 1.5 dB, with further improvement possible with a bit of tuning and some improved capacitors. I also developed a cheap negative bias circuit that is quite fool-resistant – but not Tom-resistant.

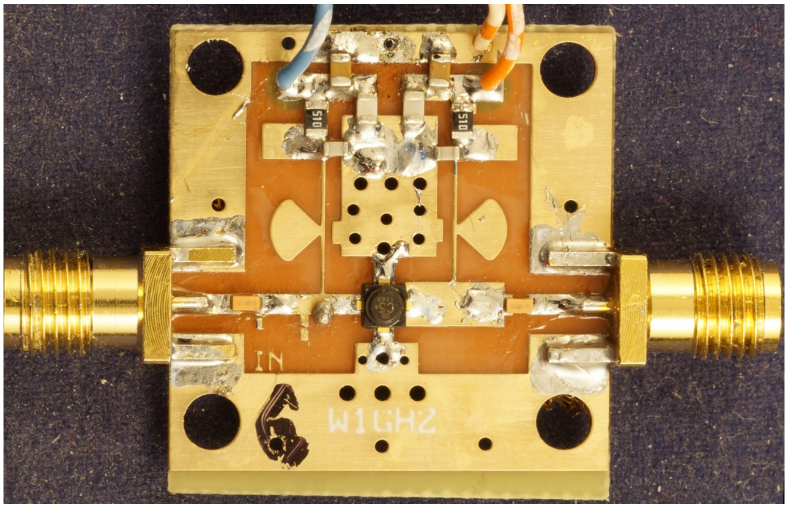

Figure 1 – 10 GHz Preamp – *Simple and Cheap*

Design Process

We don't have fancy RF software that can optimize for noise figure, so design was done the old fashioned way. Paul took the S-parameters and noise parameters, plotted them on a Smith Chart, and made some guesses about microstrip circuits. We drew up three variations of PC board plus the 50Ω lines, shown in Figure 2, and ordered prototypes – all fit on a single board. Testing showed that none of them was quite right, but they have good gain, more than 12 dB, reasonably close to the 13.7 dB spec.

These are low cost PC boards, on ordinary FR-4 type material. Board thickness was 0.6 mm, the thinnest readily available. Ultimate performance was not the goal, just a noise figure consistently under 2 dB with no tuning, to improve receive performance at low cost, so that folks with minimal test equipment can improve their system (and hear us better!). Hams with test equipment may be able to make further improvement.

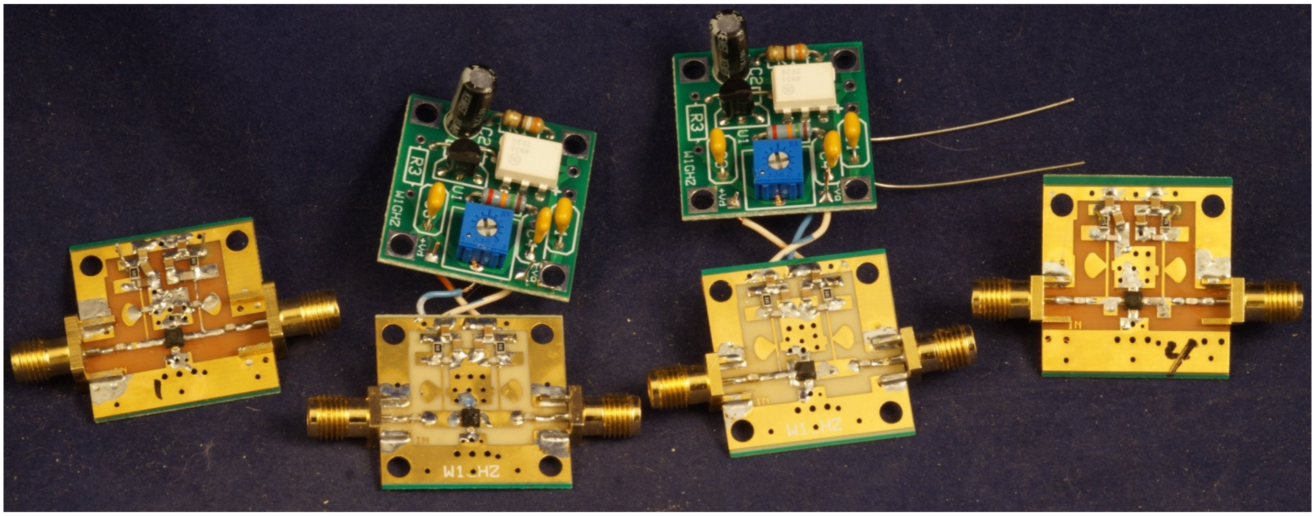

Figure 2 – First prototypes: 50 ohm lines and three others

Several NEWS Group members volunteered to try tuning up the prototypes, but only Tom really followed up and tuned for pretty low noise figure. Paul tuned a few; since 50 ohm lines had worked fairly well, he opted for minimal input tuning, by rolling short bits of wire along the input 50-ohm line. The results are shown in Figure 3. Then we gave tuned prototypes to Mike, N1JEZ, to test and see if he could improve them – he did, but only slightly.

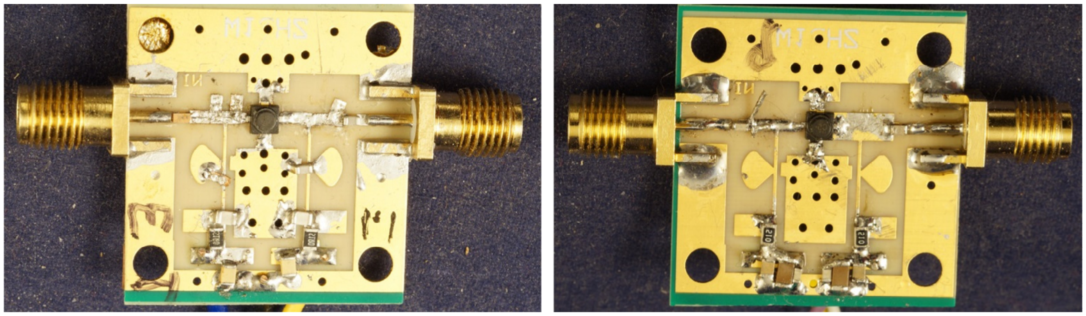

Figure 3 – Prototype tuning: WA1MBA left and W1GHZ right

We made a second round of prototype boards with both our best circuit patterns, plus one with Tom's input circuit and Paul's output pattern, shone in Figure 4. Paul's output circuit seems pretty forgiving – Mike couldn't find any improvement either. Tom's input circuit has good potential but is harder to tune, so the combination might be good.

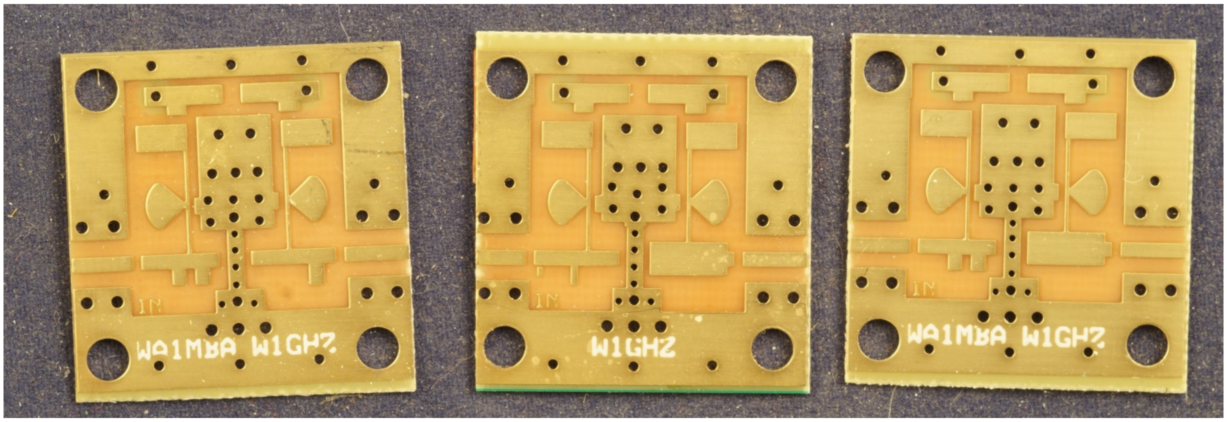

Figure 4 – 2nd Prototypes: WA1MBA left, W1GHZ center, hybrid right

The second round of prototypes work well, and are quite repeatable. Paul assembled ten boards with his circuit – all but one powered up with 1.5 dB NF and 12 to 13 dB gain; the last one had 1.6 dB NF. One simple trim of an input stub consistently improved the noise figure. The final improvement was to add high-quality blocking capacitors in the RF path, which brought the best ones down to NF of 1.2 to 1.3 dB. Mike has assembled an additional five boards, with similar performance. The schematic diagram and assembly photo are shown in Figure 5. We found that bypass capacitors at the radial bypass stub position on the printed circuit made no difference at all, so in the development process we eventually just didn't insert them and let the radial bypass stub do its job of removing the 10 GHz RF from the bias line.

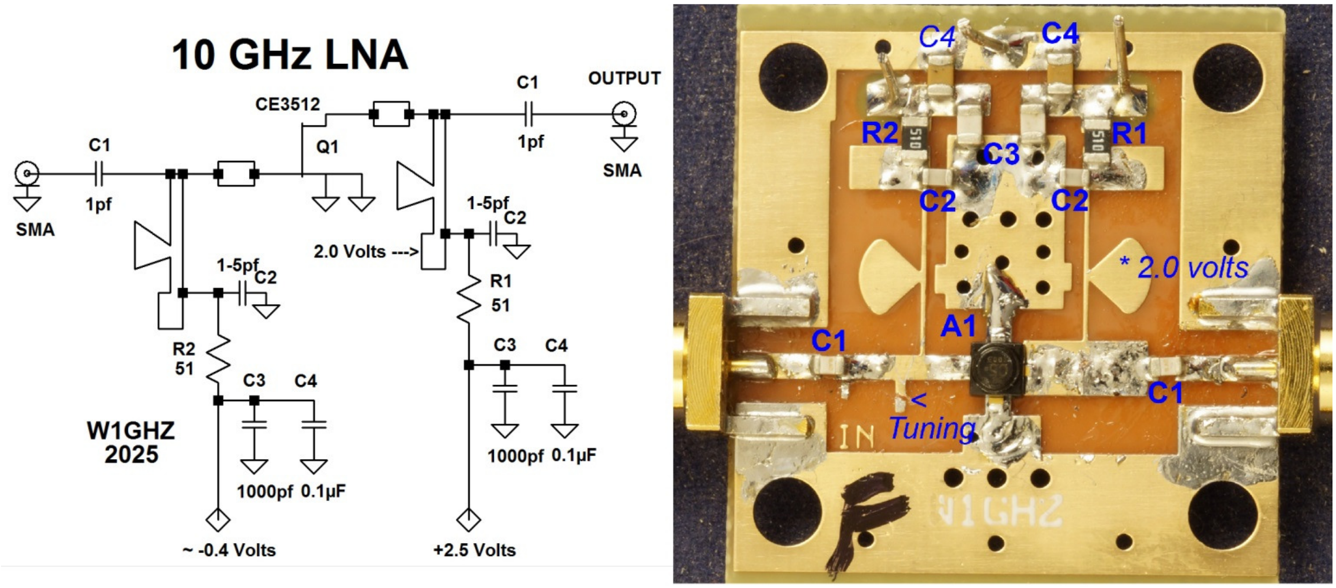

Figure 5 – 10 GHz Preamp schematic and assembly photo

Negative Bias Voltage

One problem with GaAsFETs and their fancier cousins has always been the need for negative gate bias, and insuring that the negative voltage is always available to prevent damage. I (W1GHZ) recently read a paper about using an optoisolator to produce a negative voltage and developed a fool-resistant bias circuit using one (separate paper[2]). The bias board powers the preamp as shown in Figure 6.

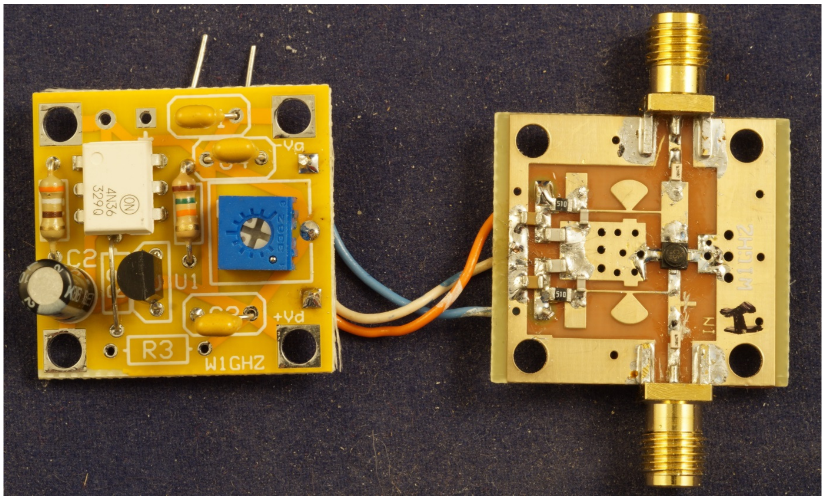

Figure 6 – 10 GHz LNA with Negative Voltage Optoisolator Bias Board

Capacitors

Paul had evaluated a bunch of capacitors for loss and high self-resonant frequency, and chosen one type, the Kyocera AVX 06035U1R0BAT2A, that is readily available at reasonable cost. These capacitors were used in the initial build of all the prototypes. Tom had a sample kit (a conference prize) of high-performance microwave capacitors, the Kyocera AVX 500s series. (Some of these parts are still listed under the ATC – American Technical Ceramics - branding.). He replaced the input capacitors on units he was testing with 1 pf 500s capacitors on units he was testing and found improvement. The part number for the 0603 1.0 pf +/-0.1 pf is 500S1R0BS100XT. Further testing by Paul showed that replacing the blocking capacitors with 1 pf 500s capacitors provided up to 0.2 dB improvement, a significant amount when we are talking about very low noise figures. Unfortunately, the ATC 500s capacitors are almost unobtanium – Mouser lists them at about $3 each but only one value, 2.7 pf, is available.

Looking for alternatives, Paul tried some ATC 600s 1 pf capacitors from another sample kit (another conference prize). These were nearly as good as the 500s, but are also hard to obtain. On ebay, I found a modest quantity of 2.0 pf ATC 500s capacitors, enough for a number of LNAs. These are also nearly as good as the 1.0 pf.

The 500s series capacitors are more difficult to solder, since they only have pads on one side, and the pads are more fragile than standard capacitors. The ATC 600s capacitors have end terminations for soldering like ordinary 0603 capacitors.

If you can find a Kyocera AVX (or olderATC) 500s or 600s sample kit, the values from perhaps 0.8 to 2 pf should give decent performance, and one kit can make a bunch of preamps if we share them. W1GHZ can provide the 2.0 pf ATC 500s while the supply lasts. Otherwise, the AVX 06035U1R0BAT2A provides very good performance and is readily available from Mouser. We recommend using them for initial assembly. After initial testing and tuneup.consider upgrading.

Construction

The input trace and ground metal on the board should come to the edge of the board – the thin board is easily trimmed with an X-Acto knife. For the 0.6mm thick PC boards, Paul was able to locate a few SMA edge connectors but hasen't tried them yet, preferring not to use anything that is not readily available. Instead, I use the Taoglas edge connectors designed for 0.8mm (1/32 inch) thick boards and shim them on the back side with thin copper or brass, or even wide solderwick. Soldering them with the shims proved tricky, so I use a razor blade as a temporary shim to hold the connector in place while soldering the top side, shown in Figure 7. The blade wedges the connector in place and solder doesn't easily stick to the steel. Once the top side is soldered, the razor blade is removed and the shim slid in and soldered in place. To ensure a short ground return path, make sure there is a solder fillet between the metal on the PC board and the connector body.

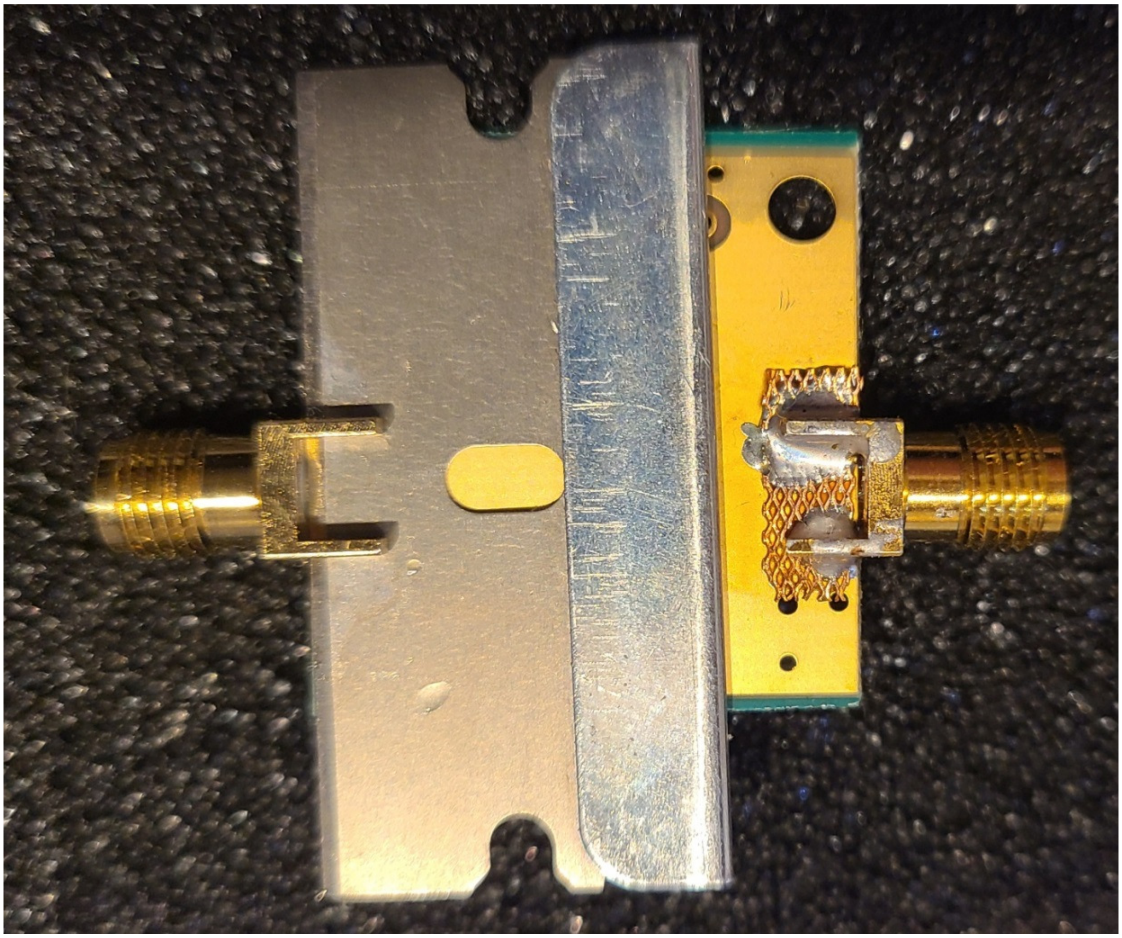

Figure 7 – Shimming for soldering SMA edge connectors on very thin PC board

Tom first used some connectors of unknown origin and discovered they added nearly 0.5 dB to the noise figure. He switched to the Taoglas variety that Paul was using. Tom used a similar procedure for mounting but slightly different. First, he tinned the backside of the board very slightly in the area where the SMA legs would go, and snugged solder wick between the legs and the board bottom to bring the legs and center pin in contact with the top of the board circuits. Then he soldered the top of the board (legs and center pin). He followed that by soldering the wick to both the legs and (the slightly pre-tinned) board bottom. We also found that shortening the center pins about one millimeter before mounting helps leave room for easy soldering of the input and output capacitors. Tom was unable to get consistent snipping of that pin using wire cutters and instead held the SMA in a small vise and trimmed the pin with a Dremel tool and appropriate cutter wheel. Your experience with small parts manipulation may vary and perhaps you will come up with better ways of mounting these affordable and easily found quality connectors.

Instead of using shims, Mike solders the connectors to the top side of the board, and then crimps the bottom SMA contacts down to the board before soldering.

The small thin PC boards heat up quickly and get rather hot while soldering the connectors, which takes a while. After a couple of bad devices, we wondered if the low-noise FET was being damaged by excessive heating. Since then, we have installed the connectors first and the FET last. The edges of the FET package should line up with the ends of the transmission lines – see Figures 1 and 3.

These FETs in their standard plastic package are not hermetically sealed. For the most part, this is not very important. However, rosin used during soldering should be removed with isopropyl alcohol or other solvent to prevent changes in impedance and loss (and poor noise figure) if left to harden and collect moisture from the air. Those solvents can enter the package and have the potential for causing problems in the future. Mounting all other parts first and doing board cleanup before mounting the FET is strongly advised. Then, care should be taken to use minimum soldering necessary for the FET and cleanup with minimum solvent and wicking quickly to draw the solvent away from the FET. Tom prefers to sharpen the non-cotton end of a swab stick with a razor blade or scalpel and use that to carefully dab on the solvent and use chem-wipes or paper towels to draw the solvent/rosin mixture away. Persnickety? Yep. Necessary? Maybe not. (Paul just uses low-residue solder and leaves it alone – cleanup made no difference.)

Tuneup

The safest way to tune up is using the optoisolator bias board to power the preamp, shown in Figure 6. The bias board limits current and voltage to the FET to prevent damage – you can reverse voltage, mix up the connections, or short out the circuit while tuning. Before powering up, make sure that both RF input and output are terminated with 50 ohms or the preamp may oscillate.

Apply power to the bias board and adjust the pot for 2.0 Volts on the FET drain – measure on the radial stub, near point * on the assembly photo, Figure 5. If the voltage will not adjust, the preamp is probably oscillating – make sure it is terminated.

Now it is time to try it with RF. Listen to a signal and see if the preamp makes a difference. If you can measure noise figure, go ahead. Poke around with a small snowflake twiddlestick, like a bit of copper tape on the end of a wooden Q-tip, or on a toothpick for fine tuning. Probably the biggest improvement will be trimming the input stubs.

If you don't have noise figure capability, trim the longer input stub with an X-Acto knife, as shown in Figure 5. If the smaller input stub is connected (some versions have it disconnected), trim it at the transmission line.

An additional small improvement, 0.1 to 0.2 dB, is possible by replacing the blocking capacitors, C1, with the better ones described above. Remove the original capacitors, clean up with fine solderwick, and gently install the new ones. Carefully clean up any rosin residue, try to keep solvent away from the FET.

Housings

The PCB construction is quick and easy for experimenting. However, even with the shims, these amplifiers aren't very robust. We are probably going to connect them with semi-rigid coax and put some stress flexing the PC board. One solution I (W1GHZ) have used for thin small boards is to mill out an aluminum clamshell package like Figure 8. The slots for the SMA connectors are very slightly undersize so that the connector is clamped behind the threads and the PC board is suspended inside, isolated from stress from cables. Great if you have a milling machine. Mike and I made some at our local Makerspace, The FoundryVT.

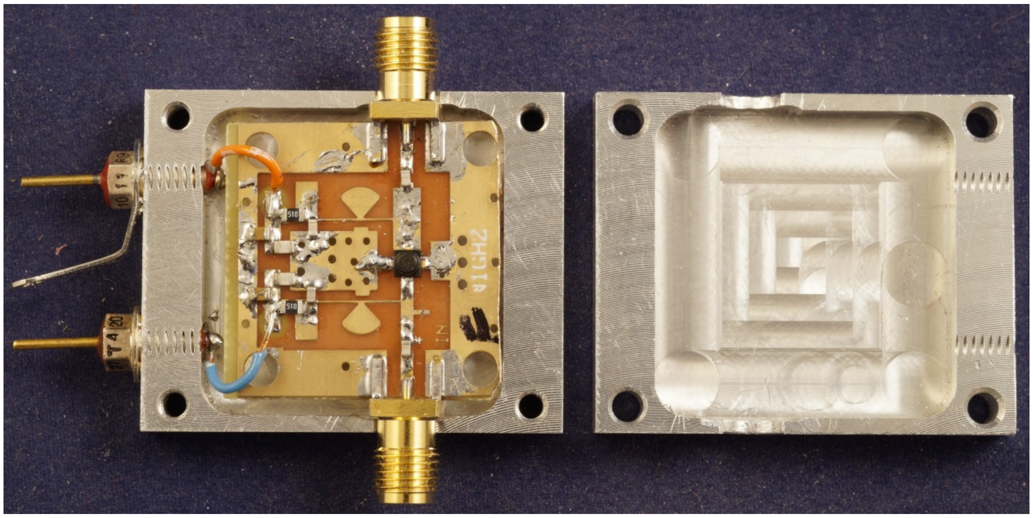

Figure 8 – Clamshell housing to reduce stress and flexing of thin PC board

The bias board can be mounted on the outside for a complete assembly, as shown in Figure 9. It could be inside as the housing, but that would require more machining and more metal.

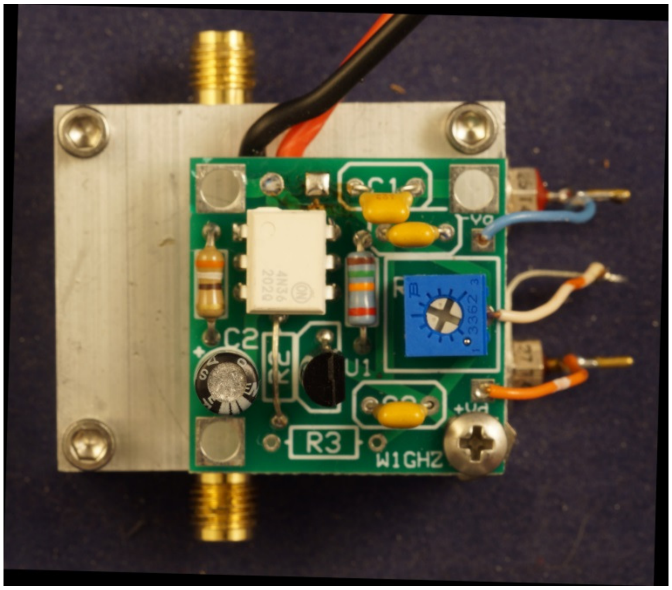

Figure 9 – Optoisolator bias board mounted on clamshell housing

Another more robust assembly technique that seems easier for building with hand tools is wrapping copper foil under the SMA connector, as Down East Microwave used for older 3-watt amplifiers. Thin foil (1/2 mil copper) is soldered to the bottom of the PC board near the connectors and folded down over a thick base plate. The PC board is clamped between a thick base plate under the board and a square ring pushing down the outer rim of the board with clearance slots for the SMA pins. The assembly, shown in Figure 9, is held together by 4-hole SMA connectors and screws which go through holes poked in the foil and into threaded holes in the base plate. The top ring is clamped in place during assembly and held in place by the top two screws for the SMA connector. The PC boards are one inch square. From the hardware store, ¼ by 1 inch aluminum bar and 1-inch square aluminum tubing with 1/16 inch wall fit the PC board, and 4 feet of each will make a lot of amplifiers. The PC board thickness is accommodated by adjusting the hole positions.

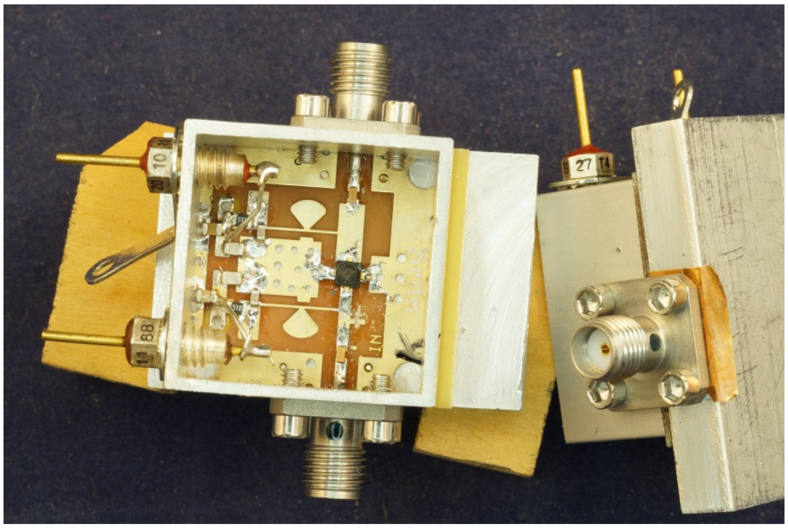

Figure 10 – Preamp housing with foil wrapped under connectors

Another assembly technique that microwaves have been using for years is to wrap the PC board with thin brass and solder the perimeter of the board. An old Zack Lau (W1VT) preamp using this technique is shown in Figure 11. It works fine, but it takes a lot of heat and flux to assemble, and a lot of cleaning to get the flux out of the box.

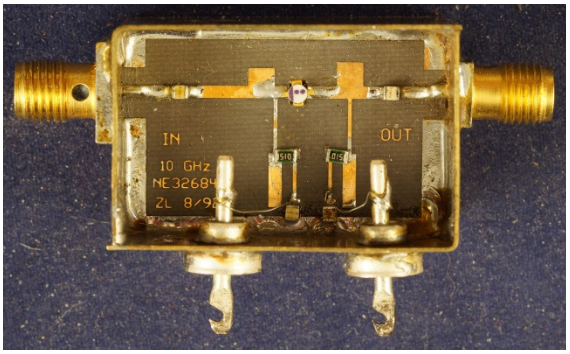

Figure 11 – Amplifier assembly wrapping thin brass around PC board and soldering perimeter

A simple assembly like bolting the PC board to something more rigid, like a scrap of thicker PC board, might be robust enough for some systems. Amateur ingenuity can probably find a solution.

Noise Figure

Disclaimer: *Measuring low noise figures accurately is difficult. None of us has recent traceable NF calibration. Our noise sources have calibration tables or charts with big increments, so we each took our best estimate. We also passed around a set of comparison amplifiers, one of these preamps plus some higher NFamplifiers, and two isolators. Each of us measured each amplifier and then measured again with an isolator on both input and output of each amplifier to reduce mismatch error. The preamp measurements were reasonably close, suggesting that the noise figures cited are perhaps ±0.25 dB. The higher NF amplifier measurements had more variation.*

We finally got a warm dry day in March with some areas clear of snow. Paul was able to set up outside and make some CS/G (Cold Sky to Ground) tests, measuring the noise increase from cold sky, perhaps 20K to warm ground, ~280K. This test, using the Total Power program by I0NAA and an RTL-SDR, does not depend on equipment calibration, and almost all errors result in a higher noise figure reading. Noise Figures ranged from 1.24 to 1.52 dB. Retesting the same units on the NF meter gave slightly higher readings, within 0.1 dB of the CS/G readings.

As an additional check, I gave one preamp to Iban, EB3FRN, while I was in Barcelona in March. He has much better NF equipment. His reading on that LNA was 1.50 dB vs my reading of 1.30 dB.

Thus we are pretty confident that our NF measurements are within ±0.2 dB, and these preamps are pretty good.

System Noise Figure

For weak signals, one of these preamps, with a noise figure under 1.5 dB, will be a significant improvement over the barefoot simple and cheap transverter, and some older transverers as well. The transverter noise figure is perhaps 8 to 10 dB. A cascade calculation (https://www.microwaves101.com/calculators/859-cascade-calculator) with roughly 13 dB of preamp gain suggests a system noise figure around 2 dB, excellent for terrestrial work. This works best if the LNA is very near the feed. Even with the best preamp, a long cable between the feed and the LNA will add a couple of dB of loss and raise the system noise figure to a higher number

An impedance mismatch, especially at the input can make a difference, and so your antenna feed match, if not 50 ohms resistive is likely to result in a different system noise figure than you would calculate (it could be worse or better). Paul makes all NF measurements with an isolator at the LNA output.

Adding a second preamp stage can improve the system noise figure, but I wouldn't dare put two in the same box.

Stability

As mentioned under Tuneup, the preamp will probably oscillate if the input and output are both unterminated. More important is that it does not oscillate with an antenna connected – an antenna is usually a good match near the operating frequency, but is an unknown impedance out of band. As a test, the noise source is connected through a 10 dB directional coupler, so the indicated noise figure is 10 dB higher with a 50 ohm load at the input. Then the load is replaced with a short and an open, representing worst cases – a sliding short would be better to check all phases. The indicated noise figure changes with the short and open, as expected, but if there is no oscillation the preamp is reasonably stable

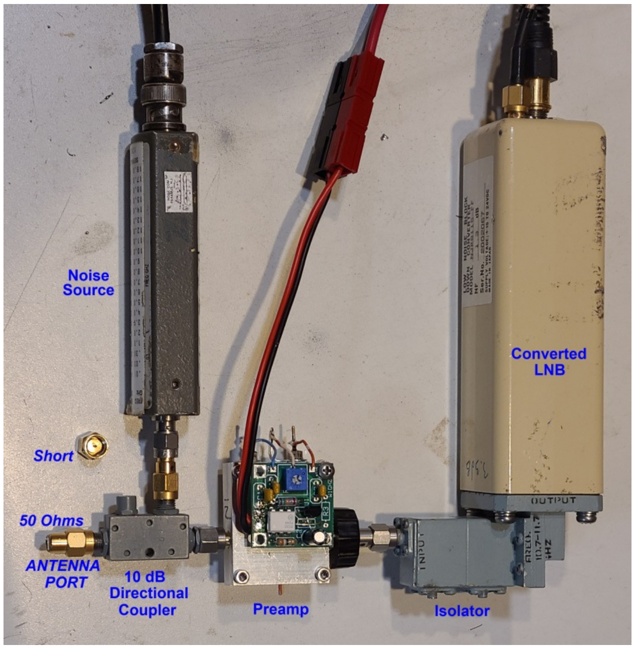

Figure 12 – Stability test setup

Summary

This simple and cheap preamp can help you hear better on 10 GHz. It is easier to build than the transverter. Assembly is within the capability of anyone doing microwave circuit board assembly with SMD parts. Total cost, including bias circuit, is in the neighborhood of $15 – we didn't make the $10 goal because the better SMA connectors are about $7 for a pair. PC boards are available for both preamp and the bias circuit.

NOTES:

1. Paul Wade, W1GHZ, "Very Low-Noise Unconditionally Stable MMIC Amplifiers," 47th Eastern VHF/UHF/Microwave Conference (2024), http://www.newsvhf.com/conf2024/PresPapers/W1GHZ-Very_Low_Noise_Unconditionally_Stable_MMIC_Amplifiers.pdf
2. Paul Wade, W1GHZ, "GaAsFET LNA Bias – Simple, Cheap, and Fool-resistant," *Proceedings of Microwave Update 2024*, ARRL, 2024, pp. 113-115. Also https://www.w1ghz.org/Preamps/GaAsFET_LNA_Bias-Simple_Cheap_and_Fool-resistant.pdf
3. https://i0naa.altervista.org/index.php/downloads

Suggested Parts List for 10 GHz Preamp Boards

Designator	Value	Mouser #
C1	1 pf	581-06035U1R0BAT2A see note
C2	1 to 5 pf	Not critical – could be same as C1
C3	1000 pf	80-C0805C102K2GEAUTO
C4	0.1 µf	80-C0805C104K1REAULR
R1	51	660-RK73B2ATTDD510J
Q1	CE3512K2	551-CE3512K2-C1
SMA	12.4 GHz	960-EMPCB.SMAFSTJBHT

Note – slightly better performing alternatives for C1, if you can find them:

1. Kyocera AVX or ATC 500s 1.0 pf (0.8 to 1.3 pf)
2. Kyocera AVX or ATC 500s 2.0 pf
3. Kyocera AVX or ATC 600s 1pf (0.8 to 1.3 pf)