Microwave Update 2000
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Future Designs of Microwave Transverters

With the increasing use of the general publics communication systems such as Cellular, PCS, WLAN, Blue Tooth, and the future use of the ISM bands, amateur band microwave transverters that were designed 5 years ago will soon ,if not already, become inadequate. Caused by the increased RF density surrounding and sharing our amateur bands, transverter designs that provided weak signal sensitivity without strong signal immunity or selectivity will soon be of little use to the Microwave enthusiast. This paper will review new design criterion such as specifications and components that are now available that will be required to produce a simple state of the art microwave transverter. This paper will also demonstrate the procedure of developing this microwave transverter that will survive today's higher density RF environment s from concept to finished product, while still producing it economically. The presentation of this paper will discuss all of the above mentioned aspects and include the manufacturing phases of the project.

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Microwave Transverter History

The microwave transverter predecessors, separate receive and transmit converters, are somewhere around 40 to 45 years old. In the beginning, receive converters with tubes for the oscillator/multiplication circuitry and diodes in 1/2 wave coaxial line assemblies produced receive noise figures of under 15 dB.[1] This was feasible, if the correct diode was selected and was biased precisely, noise figures crept down under 10 dB. With the introduction of interdigital filters,[2] most hams that were having difficulties with images, and out of band harmonics generated by the local oscillator circuitry, solved most of their problems. If you did manage to get something to work by hand machining a ton of brass, drilling and tapping a thousand holes, and carefully testing diode after diode to find "the magic one" that would net a sub 10 dB noise figure, your receive system was considered at the brink of technology!

Solid-state versions of these receive converter designs began to show up in the early 70's. [3] Also at this time, solid state LNA's appeared boasting noise figures of 5 dB or less on 1296 and 2304. [4] EME stations were popping up all over the world and contacts were made routinely by the few on the bands. Transistors were still only new to the receiver side of the system but were improving every day.

Transmit signals were accomplished by multiplication schemes where tubes were used for low level signals. It was the easiest way. The mid 70's saw solid state components, mainly varactor diodes [5],start to replace tubes one by one except for large power amplifiers. After many have tried to string varactor multipliers together to drive unstable high power tube amplifiers [6], the transmit converter was starting to be a good idea. Transverter designs for VHF and UHF were very popular and were being produced commercially. The mid to late 70's saw microwave transverter designs (23 cm) show up in journals and commercial production. Looking back at it now, it seems that the microwave transverter as we know it today, could have been more common allot earlier in history but because of the lack of transceivers versus separate receivers and transmitters, there wasn't a desire to have both microwave receive and transmit converters sharing a common local oscillator.

The first microwave transverters became the "shot in the arm" the hobby needed. When they were tuned correctly, and used as specified, they provided many first contacts and worked flawlessly! (or until the temperature changed!) The receive sections were adequate, but lacked the selectivity a multi-pole interdigital filter could provide and were down on sensitivity due to the use of "lossy" transmit/receive switching circuits and low gain receive amplifier circuits. As with the transmit section, they worked well if the first gain stage didn't think it was an oscillator! If you built one of these published designs yourself, all of the adjustments would need to be done with a bench full of test gear. It was considered "real hamming" getting one of these working on your ham shack test bench!

In the early to mid 80's allot of technical advances were made because of the up and coming cellular industry. Major break-through products designed for 1 GHz. of operation became common. A "Experimenters Band" on 33 cm opened in the United States. With Hybrid power modules, sub 1 dB noise figure GaAs FET's, and RF design software all leading the way for economical packaged double balanced mixers, affordable RF circuit board laminates and Monolithic Microwave Integrated Circuits[7] (MMIC's). If you were interested in the new band you had a copy of W0PW 902 MHz. notes[8]. And became a participant in the next renaissance of microwave amateur radio operation!

With the birth of the "No-Tune" transverter[9], every one was doing it! If you new how to solder and use a volt meter, you cold get on the microwave bands over night. Various manufactures made Kits available for all microwave bands. Solid-state power for above QRP status became more obtainable. Yagi design was becoming popular and the quest for useful and better noise figure LNAs produced countless designs[10], and "How too" articles covering every manufactures design notes. Commercial manufactures pushed the envelope higher and higher. Off the shelf 10 GHz. transverters were there for the asking in the late 80's. Could this get any better?

Well, it did for a while. The 90's brought about the technical changes that enabled transverter designers to pick and choose the components they wanted to produce the specifications required at the price they were willing to pay. There became so much selection available, that many designs were interchangeable from band to band by just adjusting the frequency of the local oscillator and band pass filters used. In doing so, the filters used became generic[11] and as long as they didn't pass the LO signal on the transmit chain, they were deemed adequate. With this simplicity. If you didn't get on the microwave bands by now, you just weren't interested. But with this simplicity came other issues.

As we moved from the mid 90's to the present, depending where you lived in North America, personal communication activity either just became present or has become overwhelming! Receive converters in amateur microwave transverters that were designed for lowest noise figure could have input filter bandwidths as high as 120 MHz. This "loose filtering" allows neighboring personal communication services to overload your sensitive converter. The lack of selectivity of MMIC's in the gain stages used that are capable of generating gain through 6 GHz., combined with mixer saturation, soon became a reality the second your daughter used her cordless telephone.

Now the good and the bad. Component manufactures are exploiting the ISM bands through 6 GHz. and exploring higher frequencies. We now have plenty of components to choose from but so do the personal communications manufactures. Surface mount technology has finally become the standard of most assembly processes. Low noise amplifier designs are becoming better every day. PHEMT's are not only lowering the bench mark for noise figure, but manufactures are designing higher IP3 performance into the smallest packages ever. Mixer manufactures are also reducing the size and increasing the frequency range and IP3 performance. Band pass filters, helical or ceramic, are smaller and available for just about any frequency between 1 and 6 GHz. Receiver, power amplifier, and switching chip sets are ready to be plugged in to anyone's design. Couple this all to the fact that the cost of theses components are at a all time low. With all of this we are now ready to design something new.

The Latest Design

In the current design 903-144 transverter, the first stage LNA has a series L input GaAs FET[12] that is broadband in nature. It is followed by a 3-pole hairpin filter, a MMIC, and another filter of the same topology. The original design had the FET biased for best noise figure. The last updated 33cm version produced by Down East Microwave Inc. had the

FET re-biased for better P1dB [13] and the 2nd stage MMIC gain lowered to raise the input P1dB of the system. This allowed larger signals to pass before the total system was compressed. The trade off was a slightly increased system noise figure (still less than 1.0 dB) caused by the decrease in conversion gain and the higher biasing of the FET.

The data in Figure 1 is a pass band response curve of the latest version 903-144 transverter manufactured. It displays the pass band and gain of the 1st stage LNA alone and the pass band and gain of the complete 33cm receive chain as the mixer sees it (input to the mixer). This is not total conversion gain! This is receiver gain in and around the 33cm band. The data was recorded with an input power level set at -40 dBm at 903 MHz. This is approximately 20 dB down from the circuit's 1 dB compression point. P1dB input of this circuit is -22dBm. Output is +0 dBm. Data was recorded point by point then entered in to an Excel spread sheet, then plotted. This will be the method for all plots shown in this paper. Also a note about P1dB measurements made at Down East Microwave Inc. versus IP3 performance. It is more difficult for us to perform third order intercept measurements than P1dB measurements. The assumption made here is that if the 1 dB compression point is increased in any circuit, the IP3 performance will be increased. Also a rule of thumb we use is that the IP3 is at a minimum 10 dB higher than the P1dB. It can also be higher.

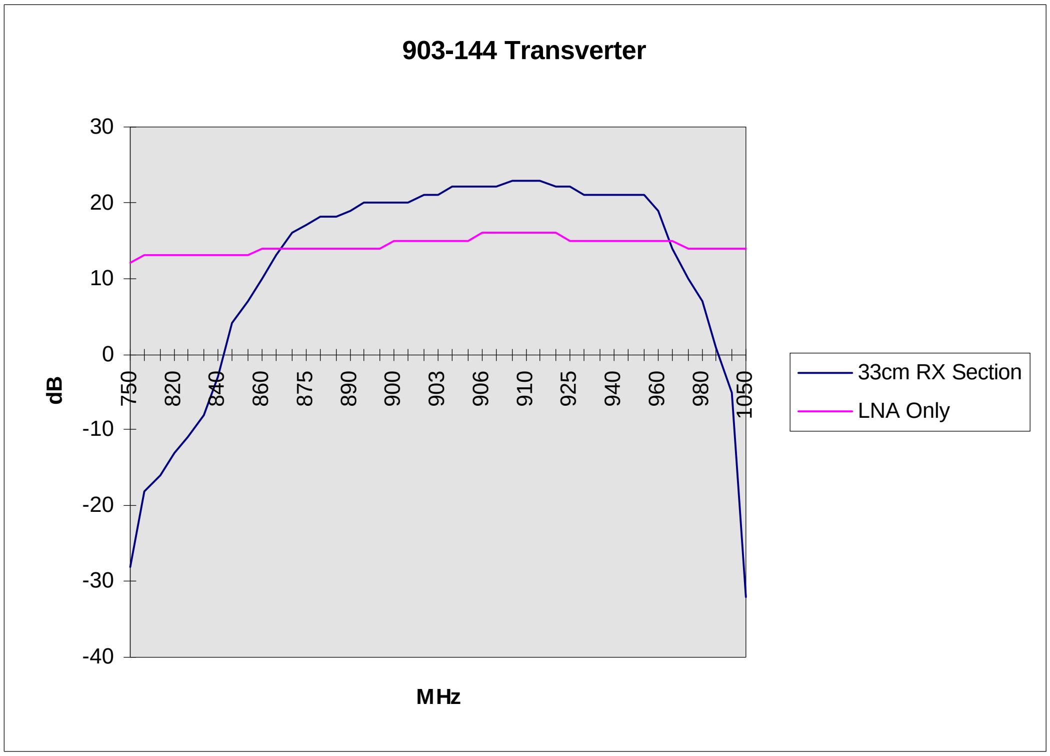

FIGURE 1.

Figure 1. shows the LNA and filters are working. Poorly by today's standards, but as designed. The P1dB test of the gain stage / filter section verified that the mixer and gain stages were matched. (the output P1dB of the gain stages equaled the P1dB input of the mixer). Saturation will occur eventually and it would be acceptable to have all components hit there limits at or about the same time. Of coarse it would get real bad real fast when it

happens, but it would need to get to that level first. Is this being optimistic? Well that's the theory at the design frequency and it tests correctly with a single frequency at the desired design frequency. Is it the same with multiple frequencies? With the LNA input circuit as wide open as it is, any signal in its amplified pass band will add to the total IP3 output of the LNA. Therefore, compression could occur much sooner in the FET than desired. The LNA may already be compressed before you try to tune in that week one on 903.1 MHz. if you live by a cell site , a 70 cm repeater , or a TV station.

The Concept of a New Design

To design and develop a new 33 cm band transverter was not just a whim. My own personal use along with plenty of customer feed back confirmed that something was needed to be done to improve the selectivity. In my own station, a stock 903-144 transverter was compressed by 3 different PCS services on a tower that is 650' from my antenna system. Placing a band pass filter on the receive input of the transverter solved the out of band interference problem. The filter had 1.5 dB loss in the pass band which increased my total system noise figure to 2.3 dB at the transverter and a total of 3 dB with the feed line used to the antenna system. I was then able to use the transverter not hearing as well as I should but hearing better than with the stock transverter. The question that now remained was if a new design was developed, how much noise figure would be sacrificed to improving the selectivity and IP3 performance of the transverter so that it would perform alone without an external filter.

It was obvious that the selectivity needed to be performed before the LNA stage. Noise figure is directly related to the loss of the input circuitry of the LNA used. What ever selectivity gained will cause the noise figure to increase. To find the compromise would be the perfect design. In addition, if we desire to raise the mixers input P1dB by 10dB (standard high level mixer over the mixer now used), we could also raise the P1dB input of the gain stages by 10 dB to further improve the transverters out of ban performance and in band strong signal handling performance. How much would this decrease the noise figure?

After reviewing the data of the current production transverter and understanding what is available in components, a list of the desired changes to a future transverter's receive section was now compiled. This is a list of everything we wanted but the time to engineer it !

1. Highest IP3 level possible for a LNA with a sub 1 dB noise figure
2. +17dBm LO high-level mixer with a +14 dBm RF level max.
3. Add a diplexier to the IF port of the mixer to improve IP# output of mixer.
4. Improve the P1dB output of the additional gain stages to match mixer.
4. Improve pass band response of both filters in the receive chain.
5. Increase local oscillator output power for new mixer.

After examining the circuit changes, and choosing the type of filters to be used, the circuit board layout required more than a “Tweek”. If we decided to do a major layout change, what other design aspects should be addressed.

1. Using helical filters requires components to be placed on both sides of the PCB.
2. It is desired to have all active components on the top side of PCB.
3. Implementation of 10 watt IF input power circuit.
4. Implementation of 200 MHz. base oscillator circuit.
5. Circuit board would be much smaller than past design. Could use a smaller enclosure.

Taking all of this into consideration, and combining it with a few emotional aspects such as the new transverter would look better if it matched the newer type enclosures used with the other microwave transverters, Sandra says “ **Do the Total redesign and get busy**!!!”

The Design

The design stage of the project, though time consuming, went rather smoothly. The basic block diagram of the original transverter did not change much except for moving a filter and adding a new circuit or two. See Figure 2. Schematically, it changed quite a bit. (not shown here as of the time of this writing) Most of the circuits that were added or changed were proven and in use already. The TX section except for the type of filtering remained the same. The 10 watt IF has been used on the Transverter Control board in all of the other microwave transverters. The 200 MHz base oscillator circuit (189.75 MHz. for 903-144) has been used for over 2 years and will incorporate the shield that the 1296 transverter utilizes. A decision needed to be made about what regulated voltage level to run the oscillator at, 9 or 5 VDC, and weather or not the gain stages in the multiplier/amplifier circuit would be on the same regulator or not.

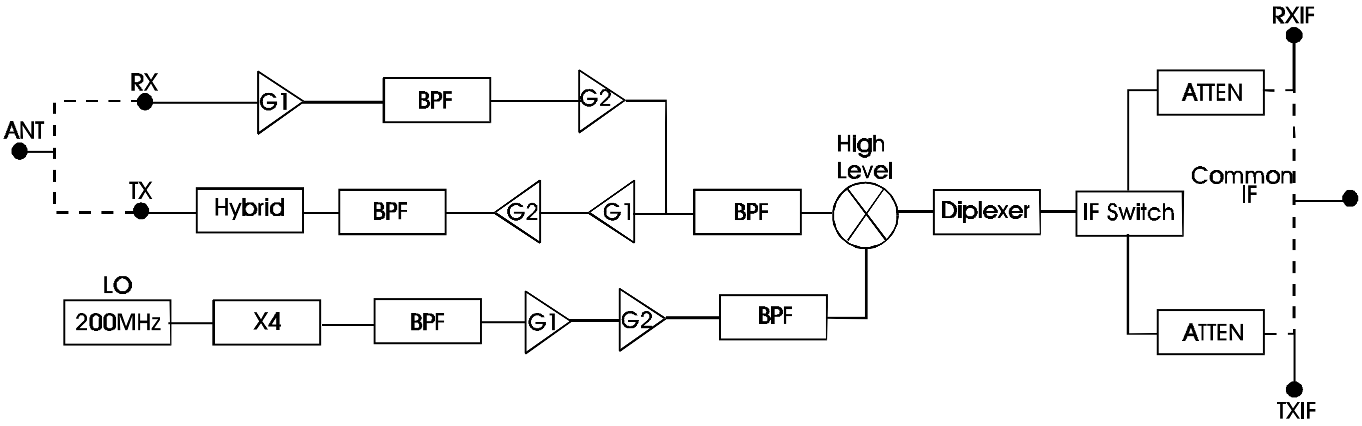

FIGURE 2.

The LO multiplier/amplifier circuit is a bit innovated. It is a adaptation of the multiplier circuit originally conceived by Jim Davey, WA8NLC[14], that we now use in all of our microwave transverters. It is an active multiplier that requires less drive than the multiplier diode circuits of the past. It's concept seems to be a step backwards in time using a active multiplier, but there are no adjustments and it produces lower level undesirable harmonics that are less likely to be generated throughout the circuit board. There wasn't much engineering required with this circuit except for building the prototype and testing the levels. The main change that was tested in the LO circuit is the placement of the last band pass filter. It was decided to place the filter directly preceding the mixer versus a MMIC driving the mixer. The out of band noise floor was noticeably lower in this configuration.

The major change over the last design was to re-design the LNA section. In the past, transverters were designed to have as much selectivity and strong signal immunity as a sub 1 dB noise figure would allow. Lets face it, noise figures sold LNA's and transverters! Well not any more! And advertised input IP3 performance isn't of any value if it becomes saturated from out of band signals first! On this next version, the advertised Noise figure will be secondary because the receive section will be designed for selectivity, strong signal immunity and noise figure in that order. Installing a multi-pole interdigital filter on the front end of the transverter is not acceptable. This can now be done with a simple design. We just need to make a few compromises in this new design.

First step was to choose a FET to do the job. We eliminated all MMIC's because of input selectivity. We did not consider the Ultra Low noise PHEMTS such as the ATF 36077, and NE32484 because of their low output IP3's. Looking at the newer surface mount PHEMT's, there were obvious choices. The ATF34143 has very low noise, and a high output IP3's with enough gain to be able to give some up for selectivity in an input circuit. A brief study was made and it was clearly a winner. If you have a chance study Agilent's App. notes[15] you will see why. BUT! Because of long lead times, future allocation problems, and that we basically found the newer SOT43 packages are very difficult to be soldered reliably by hand, we decided against it. If we use SOT43 packaged components, most of our kit builders would require us to install them in every kit supplied. We are not ready for that commitment as of now but are considering it for the 1st revision after this run is complete.

For this first design, we then chose the MES FETs that we have been using in the past. Having some expertise in rolling off low frequency gain of microwave LNA's[16], I chose to take the shunt L input approach (high pass filter), and couple it with a standard series C shunt LC circuit. Yes, a tuned circuit at 33 cm. A circuit of this type is sure to have loss at 900 MHz. So, would it be two much for this final design? We tried 2 slightly different designs with 2 different FETs (total of 4 different designs). We used the Standard ATF-10136 and the ATF-21186. For discussion, they will be called the 101 and the 211. The 101 offered more gain and a little better noise figure. The 211 was originally designed as a economical 1 GHz. FET. The 211 will soon be obsolete but we have an ample supply in stock. The 101 will remain in production for now. Five LNAs of each type were built and tested Twenty LNA's total. Their data was averaged and compiled together to produce one model each of the 4 separate LNA designs. The goal was to roll of the low frequency gain, maintain a decent noise figure in band and control what high frequency gain there was. Examine the plots in figure 3.

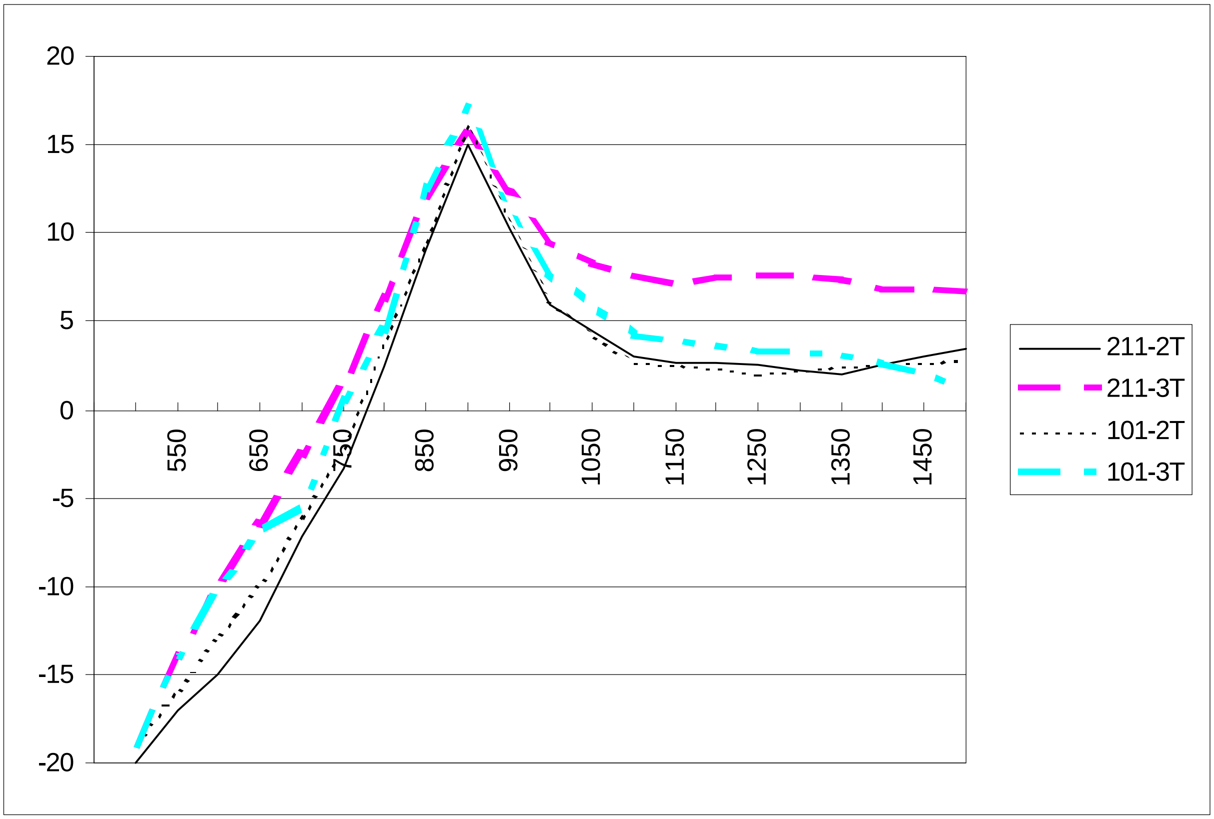

FIGURE 3.

The 2T design circuits have the best pass band with the 101 having higher gain in the frequency of interest. The question is does the gain of the 101 benefit the output P1dB. The measured data states that in this circuit with the resistive loading output and biased for 60 mA with 3 volts on the drain, the P1dB output of both designs were equal at about +14 to +15 dBm . The noise figures are also about the same. They were all between 1.2 and 1.3 dB. The data shows that the 211 has a better input P1dB by 1 dB because it has 1 dB less gain (+0 dBm input P1dB). It also is less than half the price of the 101. It is feasible that both FETs could be used for the first stage or LNA part of the transverter. See the schematic in Figure 4.

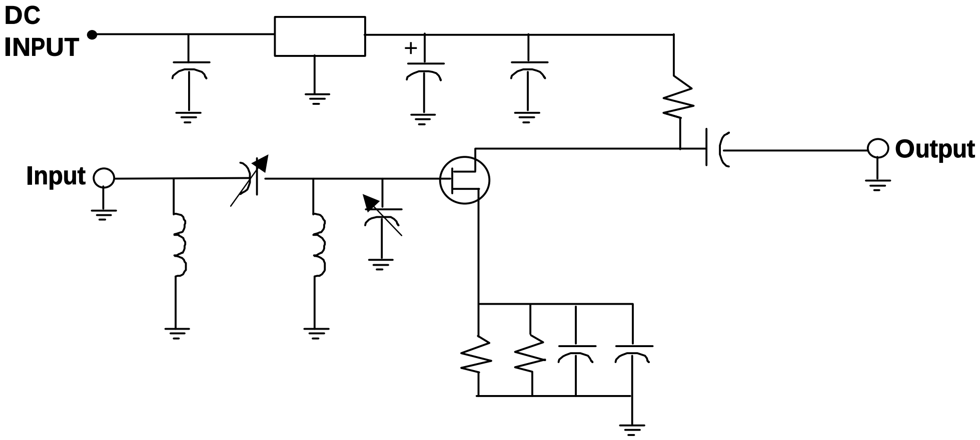

FIGURE 4.

The best part of this design so far is the difference of the pass bands in Figure 3 compared to the pass band of the LNA only in Figure 1. Figure 1 shows about 11 dB of gain at 750 MHz. With the new 2T circuit, there were negative gains at 750 MHz. The 2T circuit was accepted as is for now to continue the circuit evaluation. Future work on the 2T LNA design could include output P1dB improvements. If the gain could be increased at the same rate as the output P1dB, it would slightly improve the noise figure of the total system, but not raise the input P1dB level. Since input P1dB improvement is the goal for this transverter design, further development was not necessary at this time but will include the new PHEMT's mentioned already.

This design was accomplished with an adjustable input circuit. It was adjusted for maximum gain which doesn't net the best noise figure exactly. This design will be offered as a kit so it is important the noise figure will be close to optimum when adjusted with out a noise figure meter. The adjustable capacitors used are the new "J" series type from Voltronics[17] and the fixed inductors are from Delevan.[18] They are both low loss, high Q components designed for this type of application and make this design possible. These components will be used in higher frequency designs in the future.

Now, after examining the block diagram in Figure 2, it is noted that a MMIC gain stage will be between two band pass filters following the FET. This all precedes the high level mixer. The mixer specified has a P1dB input of +14 dBm. If we exceed this, the mixer will become saturated and produces distortion products. In order to keep a relative good system noise figure, it is imperative to maintain approximately 22 dB of RF gain in the receive section before the mixer. Therefore, we will have a 2nd gain stage in between the two band pass filters. The filter that precedes the mixer will have 3 dB of loss. The math says that a level of +17 dBm input to this filter will also be the P1dB level of the mixer (17 - 3 = 14 dBm). Good so far! If we chose a MMIC with a +17 dBm P1dB output such as a MAV-11 with 12 dB gain states that a +5 dBm input signal to the MAV 11 equals +14 dBm to the mixer. The filter that precedes the MAV-11 has 2 dB of loss. Again with the math it states that if the output of the FET exceeds +7 dBm, it will start to saturate the MMIC and the mixer at the same time. Now that we know that the FET is capable of almost +14 to +15 dBm output, it states that the FET now has 7 to 8 dB of head room. It also means that -8 dBm input to the transverter will start to saturate the system. Lets completely build, test, and evaluate the receive section stage by stage.

Since we chose the 211 FET for the LNA, we will use one of the 2T circuits that we previously built and then add a 2 pole band pass filter that we selected out of the TOKO[19] catalog to the output of it and test again. See Figure 5. It shows the LNA's pass band gain response on the top trace and the LNA with a 2-pole band pass filter on its output on the bottom trace. The 2 stages together make a good combination besting the pass band response of the original design by a large margin. Compare it to Figure 1. It is the same scale. The P1dB output of the combination measured at 903MHz is +12 dBm for +0 dBm input. This is just were it was predicted to be. The noise figure measured was 1.2 dB and the uncompressed gain measured 13 dB gain. This alone would make a great preamp for most any existing 33 cm amateur system.

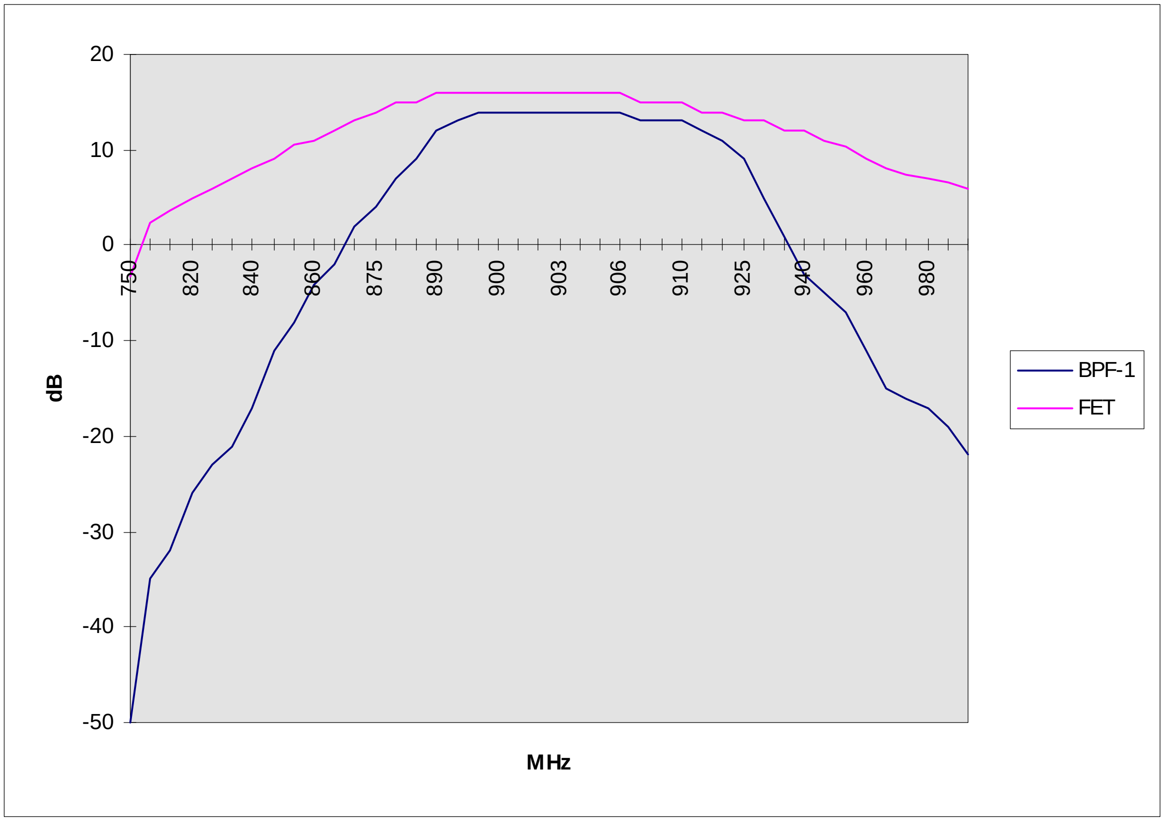

FIGURE 5.

Adding the MMIC gain stage to the output of this filter showed the expected gain increase with the same band pass of the 2-pole filter so it was decided not to record this data. It was just noted that the gain increased by about 12 dB at 903 MHz, for a total of 25 dB gain. We are on track. A check for P1dB revealed that the MMIC will start to compress at +16 to +17 dBm output. This reduces the P1dB input of the total circuit to -7dBm at 903 MHz. The MMIC compress first at levels higher than that in band. It is also important to under stand from the chart that if a large signal was introduced at other frequencies, what the effect would be to the system. At 845 MHz. the FET has 8 dB gain. The input P1dB level is then +7dBm into the FET. (+15 dBm - 8dB gain = +7dBm) That signal now passes through the band pass filter that has 10 dB of attenuation at that frequency. This means +5 dBm will drive the 12 dB gain MMIC up to +17dBm output, its P1dB level. At 845 MHz, the MMIC is not saturated as it was at 903 with a lower level signal. The difference between the 845 MHz input level and 903 MHz. input level that produces the same output level is 14 dB. This is 14dB of increased dynamic range between frequencies. Very important!!!!

We are ready to add the 2nd band pass filter, which is a 3-pole unit, and run this data again. The 3-pole filter used is centered around 915 MHz. This places the low frequency skirt higher in frequency than the 2-pole unit which was centered around 905 MHz. The effect of using the staggered filters works rather well as shown in Figure 6. The curves depict the new response overlaid on the curves from Figure 5. The narrow passband, highest gain response is the2 gain stage, 2-band pass filter response. Another point to mention is the out of band response. Gain prediction and compression levels can be estimated by using the charts at any frequency given on the chart.

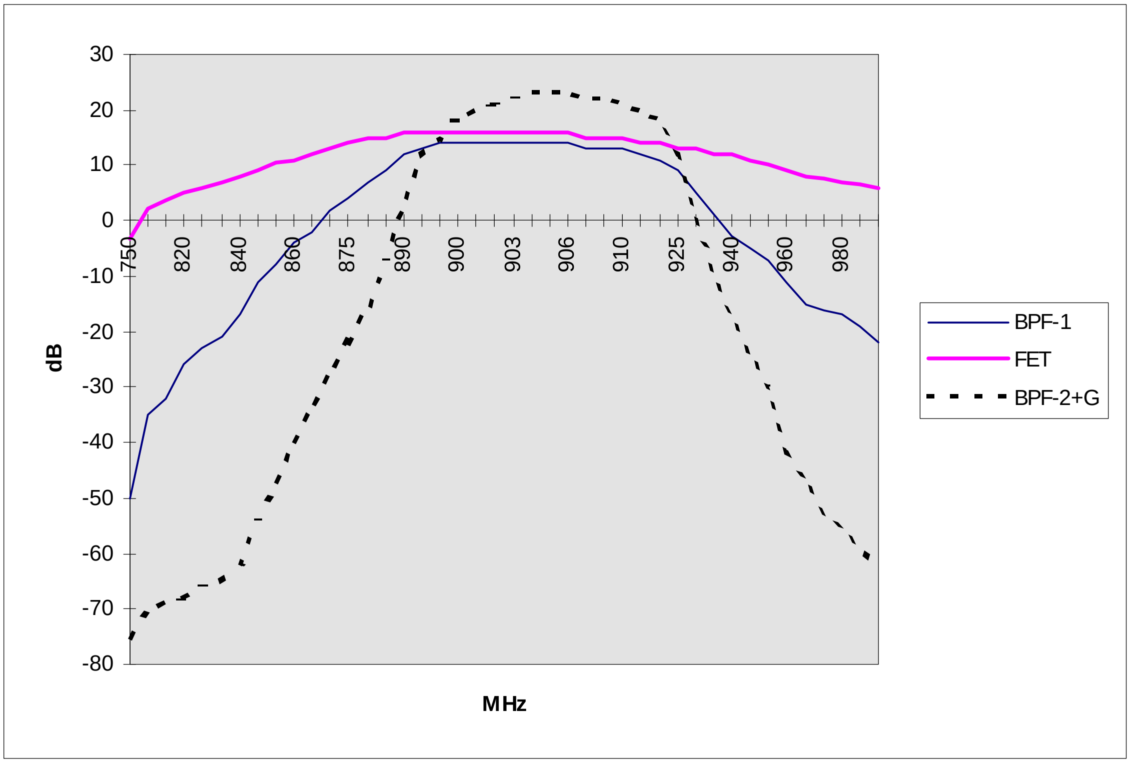

FIGURE 6.

After this pass band response data was recorded, the combination was put through some further testing. Just looking at the curves doesn't tell the whole story. Measuring P1dB's in and out of band will show the strong signal immunity aspect of the design. The P1dB at 903 MHz. remained at -7dBm input as expected. Measuring the P1dB at 880 MHz. shows that it will accept 5 dBm more input before compression starts. This means that it will require -2dBm input before the converter will start to saturate at 880 MHz. Then the best part is that at 880 MHz., it has more than 15 dB of attenuated signal that will approach the mixer. This input level could become higher and higher as the frequency delta increases from the design frequency until the gain of the FET is less than 0 and the input signal reaches the maximum safe level input without damage to the FET (50 mw). With the FET's P1dB of +10 dBm output, at frequencies other than the design frequency, it will tolerate higher input levels. So by looking at the data on the chart, If a +10 dBm signal was introduced at the input of the FET at 845 MHz. (Cellular Mobile), a level of approximately -50 dBm would show up at the mixer and the FET would not yet be compressed.

With the receive section basically designed and operating to desired specifications, a diplexier was implemented on the IF output of the mixer to be sure of having a wide band match. As of now the decision to include a IF amplifier stage or not to the transverter has not been made. It could be useful if the transverter is remotely installed but will reduce the input P1dB of the transverter by almost the full amount of the gain stage. It may show up as an option with cautions of its use. Having a adjustable receive IF gain will help but basically this transverter will out perform any 2 meter transceiver's receiver on the market today.

The transmit circuitry design wasn't changed except for the new type of band pass filters used. It was assembled in a prototype fashion and tested for spurious outputs and found to be very good. The important feature was to have enough transmit gain so that the mixer would not need to be saturated to produce the rated full output power.

With all of the other associated circuitry used in this transverter developed and used in other products, the PCB layout became the next challenge. It was accomplished and 3 revisions of the circuit board were generated before the final design was accepted. It did eventually produce the desired results without a compromise.

At the time of the writing of this paper, the final technical information of this new design was not yet available. The preliminary results are that it functions as designed in my own station and will replace a highly modified transverter with an external preamplifier and 6 pole bandpass filter. Further information will be included in the presentation of this paper at Microwave Update 2000. This paper, when complete, will be available in the library section of the Down East Microwave Inc. web site[20]. It will include the final specifications and full product description of this new design.

Final Notes

I hope the information provided so far will help many understand the threat to our hobby concerning RF density problems. I also hope it provided some inspiration of getting on and operating in these "noisy garbage bands". It has become difficult and it will not get any easier to operate on these bands in the future. For now all we can do is use the same components that the commercial industry uses but maybe in a better way. It is a challenge. All future amateur radio designs in the microwave bands need to take this challenge seriously. If we cannot prove to ourselves that we can use these bands effectively, we will stop using them. If we stop using them we will loose them permanently.

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