

Ultra Linear Low Noise VHF and UHF Preamplifiers, Dragoslav Dobricic, YU1AW

A new type of low noise preamplifier is described here, which is recommended for its exceptional noise and inter-modulation characteristics not only for normal DX operation, but also for operation under difficult conditions when there are a significant number of powerful local stations, for example during competitions. The amplifiers are designed to have low noise, unconditional stability and exceptional linearity, thanks to the use of special ultra-linear, bipolar, low noise transistors designed for TV signals amplifiers. Since they are widely used, they are readily available and low price. Construction is extremely simple with a small number of components, very simple adjustments and a high repeatability. This has been achieved using extensive computer non-linear and statistical optimisation. Designs are available for all amateur bands from 6m to 23cm [5].

Introduction

For three decades, MOS-FET or GaAs-FET transistors have been used almost exclusively in preamplifier designs. The reason for this is their superior noise performance and amplification. What we inevitably encounter when using GaAs-FETs is a stability problem due to their conditional stability on VHF and UHF frequencies [1 – 4]. However, with an increasing number of stations using greater output powers, especially during competitions, the majority of these low noise preamplifiers that are successfully used for DX, MS or EME activity, become overloaded. This is manifested by a large number of inter-modulation products that contaminate the band, this is attributed to other stations and especially those that use powerful amplifiers.

The problem, of course, could be in non-linear power amplifiers due to excess input power causing saturation. This generates a high level of inter-modulation products. However, in practice it is more frequently due to the receiver's excessively high amplification and insufficient linearity, i.e. its input stage is overloaded causing it to generate products that look as though they really

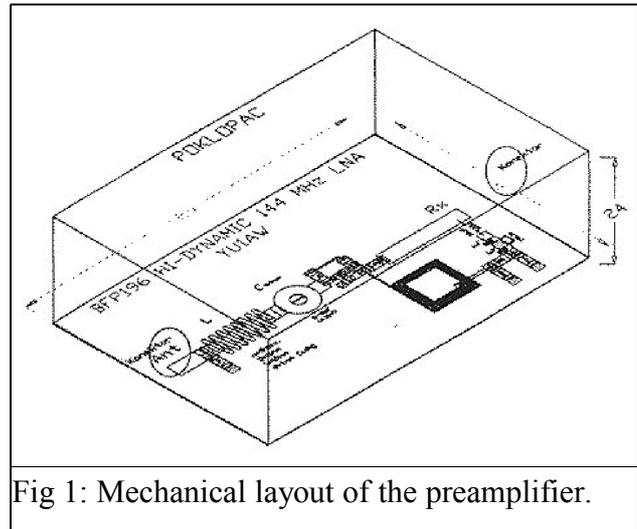


Fig 1: Mechanical layout of the preamplifier.

exist on the band.

In order to understand how to cure this problem, it is necessary to know how, where and under what conditions it occurs. It turns out that the source of this problem is very high amplification, a feature that the majority of amateurs praise the most and should be praised the least or even avoided. Technically it is much more difficult to achieve the two other important properties of an amplifier: low noise factor and strong signal performance, i.e. linearity. These are the most important properties for an amplifier to those for whom decibels are not just numbers that cover ignorance.

How do we determine which amplifier is of good quality? In order to resolve this dilemma a measure of an amplifier's quality has been introduced which encompasses all of an amplifier's three characteristics: noise factor, amplification and the output level of a signal for a determined level of non-linear distortions. This measure of quality is called the *dynamic range* of an amplifier and represents a range in which the level of a signal on an amplifier's input can be changed, while the output signal degradation stays within defined limits. The lower limit of this range is determined by the minimum allowable signal/noise ratio of the output signal and it is directly determined by the amplifier's noise factor, and the upper limit is the allowable level of non-linear distortion.

The lower limit of a dynamic range is the level of the input signal that gives a previously determined minimal signal/noise ratio (S/N) at the

output. If the lower limit value is a $S/N = 0$ (incoming signal and following noise are equal) and if the upper limit of this range is limited by the maximum output signal voltage, at which the amplifier, due to non-linear distortion, generates products equal to the level of noise on the output of the amplifier. Then this is the so-called SFDR (Spurious Free Dynamic Range) or a dynamic range free from distortion, i.e. products of inter-modular distortions or *IMD*.

Since the third order inter-modulation distortion (*IMD3*) is dependant on the cube of the input signal, i.e. with each increase or decrease of the input signal by 1dB, the third order inter-modulation products increase or decrease by 3dB. It is therefore possible to calculate the maximum output level for different values of relations between products and the signal that is being used, or the value of *IMD3* products, at different output signal levels. Using an attenuator enables us to also check whether an amplifier is overloaded, i.e. recognize whether an audible signal on our receiver really exists on the band or whether it is simply the “imagination” of our overloaded receiver. This enables us to dispose of overload and *IMD3*.

Since the level of products rise faster than the basic signal, by increasing the input signal we reach the point at which third order inter-modulation products, *IMD3*, reach the level of a useful signal at the output and that point is known as *IP3* (Intercept Point). When the *IP3* value is quoted it is necessary to state if it is referenced to the input or output of the amplifier. These values naturally differ by the value of the amplifier's amplification. Occasionally, it is stated as the *TOI* (Third Order Intercept). This point is often taken as a measure of an amplifier's linearity and is highly convenient when comparing different amplifiers. Knowing the value of an amplifier's *IP3* enables us to precisely calculate the value of *IMD3* products at some arbitrarily chosen output or input signal level.

If excessive amplification is used, for example in a multi stage amplifier, a danger exists where the aerial noise and the noise of the first amplifier are amplified to such an extent that they exceed the limit of linear operation of the last transistor, at

which point the amplifier is saturated with the noise itself without any signal.

The conclusion is clear: An amplifier is worth as much as its dynamic range value, rather than how great its amplification is!

Construction

If we want to construct an amplifier with the maximum amount of SFDR we have to fulfil the following conditions:

- make sure that the noise factor is as low as possible
- the *IP3* is as high as possible
- has acceptable amplification.

On the one hand, amplification should be as large as possible, to prevent second degree influence on noise factor, and on the other hand it should be as small as possible so that the *IP3* input is as high as possible, i.e. so that the amplifier should withstand the highest possible input signals without distortion. Compromise is essential and it usually ranges between 13–20dB amplification, depending on which parameter is more important for us.

If we want a low noise amplifier with a high dynamic range, then the choice of a corresponding transistor is extremely important. It is necessary to choose the type of transistor that besides low noise and sufficient amplification on the given frequency fulfils the condition of good linearity, i.e. high *IP3* along with unconditional stability. Hitherto, MOS-FET and GaAs-FET transistors did not fulfil this condition in a satisfactory manner. Specially built transistors for ultra linear working, primarily for CATV fulfil these criteria. For that reason, Siemens BFP196 bipolar transistors in SMD packaging were chosen. The Philips transistor BFG540/X corresponds closely to the Siemens device, it only requires slightly different base bias resistors. This Philips transistor should be used on 1296MHz because it gives several decibels greater amplification. I should stress that BFG540 without /X could be used, but the layout of pins is different, i.e. it is not pin-to-pin

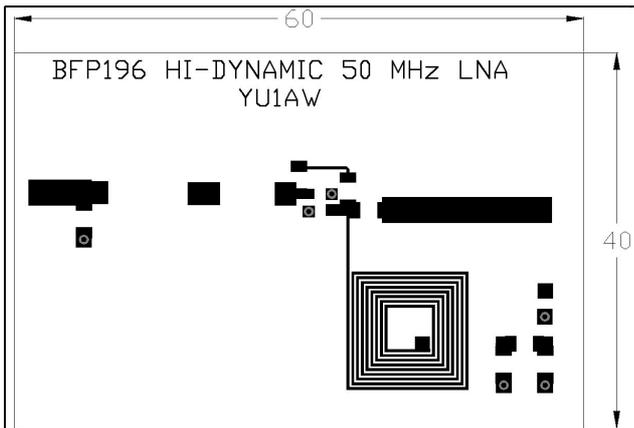


Fig 2: PCB layout for the 6m preamplifier.

compatible with the BFP196, therefore the printed circuit board has to be changed, which is not recommended.

Since we are talking about a broadband transistor whose Z_{in} and S_{11} values are relatively close to 50Ω , the input circuit has been chosen to optimally match the transistor with regards to noise, while at the same time it provides some selectivity at the input. By varying the circuit values a compromise is found which provides the highest selectivity with minimal degradation of the noise factor. On lower bands where the noise factor is not as important, the compromise was more in favour of selectivity which is more important than noise on these bands. The operating point of the transistor was also chosen as a compromise between minimal noise and maximum IP3. The output circuit is relatively broadband and it is implemented using a printed inductor to reduce coupling with the input and to provide high repeatability. In order to maintain optimal output matching that gives minimal IMD, any matching by trimmer capacitors or by variable inductances

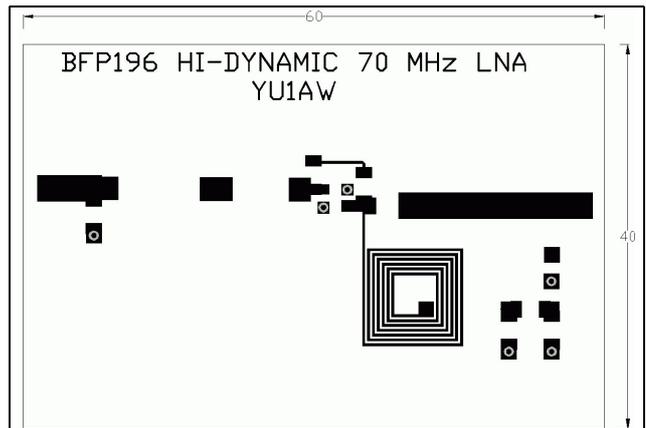


Fig 3: PCB layout for the 4m preamplifier.

is forbidden on the output. In order to achieve unconditional stability, minimal IMD, optimal amplification and minimal noise, negative feedback is applied which cannot be changed arbitrarily.

The printed circuit board is made with the dimensions shown in the relevant figure (Fig 2 for 6m, Fig 3 for 4m, Fig 4 for 2m). Double sided board, type G10 or FR4 is suitable. The bottom copper surface is an un-etched ground plane. SMD components are the 1206 type and the ground connections are made using through plated holes or with wire links through the holes soldered on both sides. The parallel resistor and capacitor in the base bias circuit are soldered on top of each other and not next to each other. The transistor collector is connected to the wider track.

The trimmer used is either of the air or PTFE foil type, although a ceramic one can also be used if it has a suitable capacity range. It is especially important for the higher band amplifiers that the

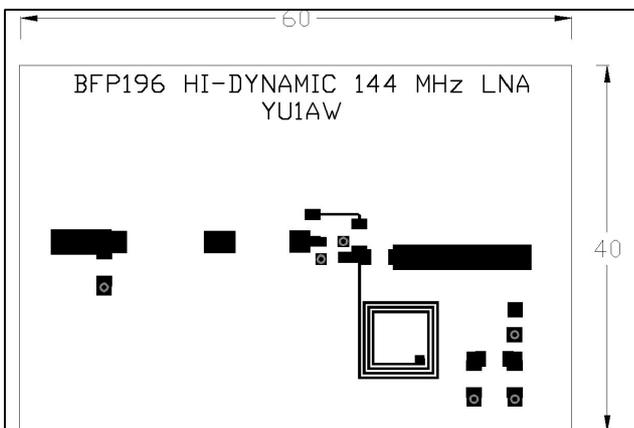


Fig 4: PCB layout for the 2m preamplifier.

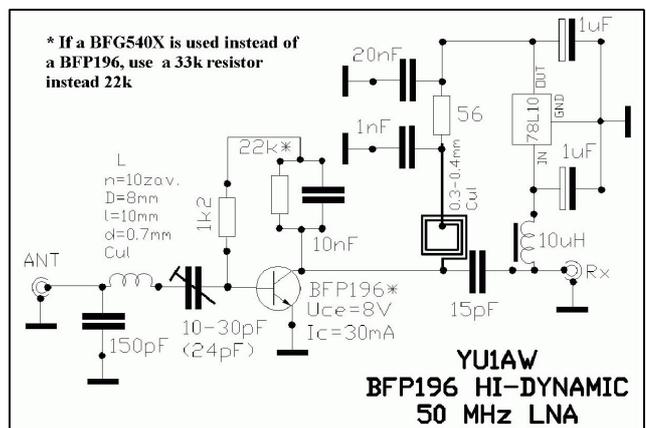


Fig 5: Circuit diagram for the 6m preamplifier.

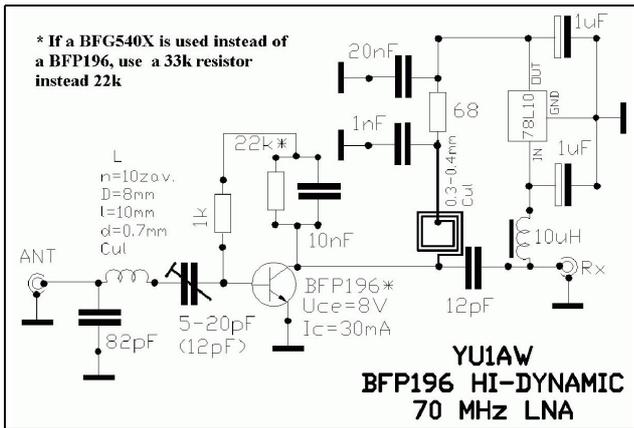


Fig 6: Circuit diagram of 4m preamplifier.

trimmer capacitor has a low enough minimum capacity.

The coil is wound, as shown in the relevant circuit diagram (Fig 5 6m, Fig 6 4m, Fig 7 2m), with silver plated copper wire, thickness “d” and “n” turns with a body diameter “D”. The coil is to be expanded to length “l”. When the coil is fitted it has to be positioned so that the bottom is approximately 3mm above the printed circuit board.

The box for the amplifier is made so that the printed board is the bottom side of the box, as can be seen in Fig 1. The easiest way to do this is to solder 25-30mm wide copper or brass strip, 0.3mm thick, around the edges of the printed board. Connections are mounted onto the box created, and a lid is made out of the same kind of sheet metal.

Once everything is carefully soldered, check for any possible mistakes such as short circuits. Then connect the DC supply voltage and measure the collector current and voltage. If everything is correct and properly connected and the transistor

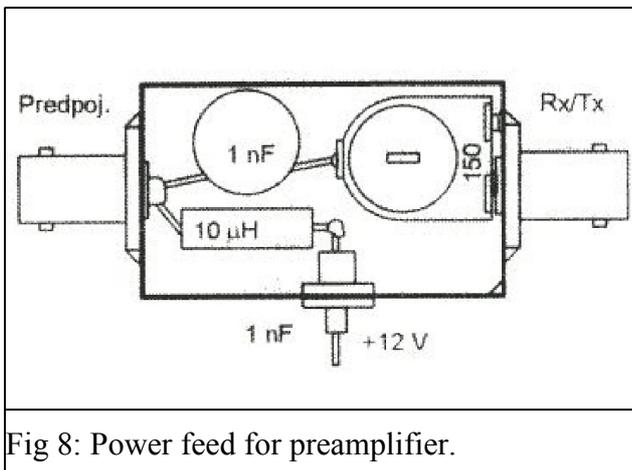


Fig 8: Power feed for preamplifier.

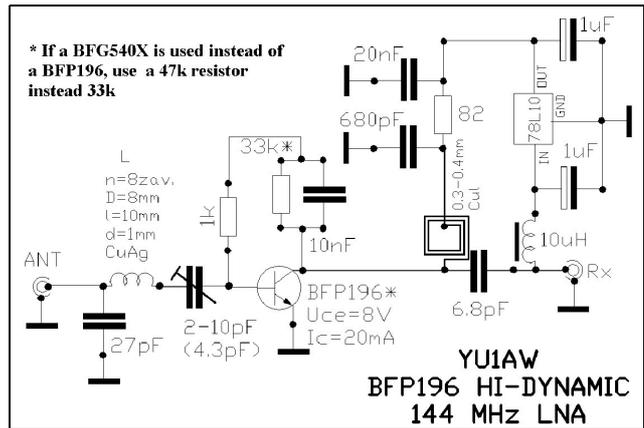


Fig 7: Circuit diagram of 2m preamplifier.

is functioning properly, the values should be close to the ones given in the circuit diagram. If the differences are within 10%, everything is OK. If the differences are greater, check the supply voltage and then reduce the value of the base bias resistor, which is in parallel with the capacitor. Make it lower to raise the collector current and vice-versa. Do not change the value of the other resistor in the base bias circuit. If the collector voltage is not correct at the correct value of collector current, adjust the value of the resistor in the supply line. Such corrections are extremely rare and are necessary only if the particular transistor used has different characteristics from the common characteristics for that transistor type.

When both collector voltage and current are within the expected range, connect an aerial to the amplifier input and the receiver to the output and adjust the trimmer capacitor for maximum received signal using a weaker station. This completes the final adjustment; the performance

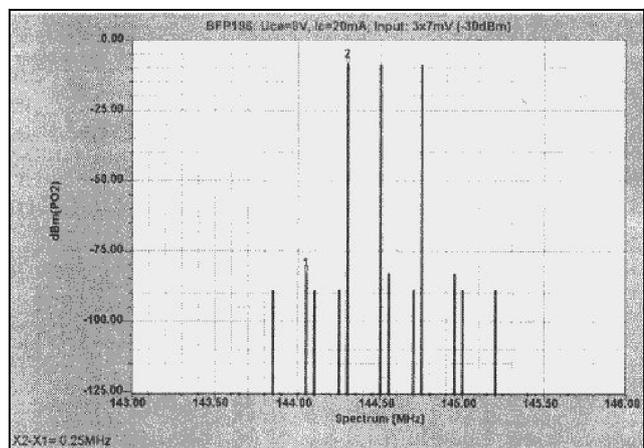


Fig 9: IMD products from a BFP196 preamplifier.

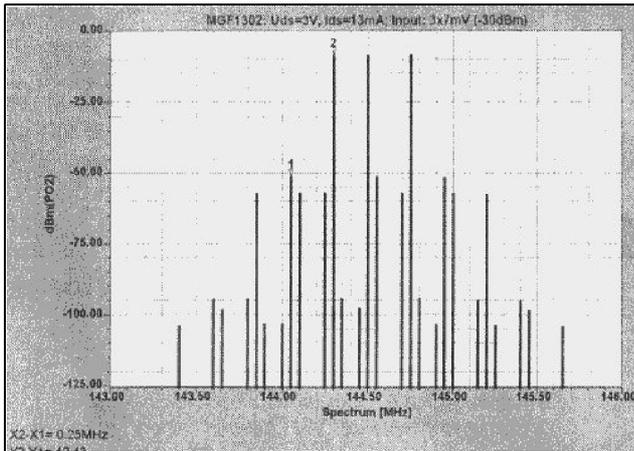


Fig 10: IMD products from an MGF1302 preamplifier.

will be very close to the predicted values. With higher band amplifiers, especially 23cm, there is a slight difference in matching for maximum amplification and for minimum noise. The amplifier should be set to maximum amplification and then adjust it to a slighter lower frequency, i.e. slightly raise the trimmer capacity, until the amplification falls by 1-2dB.

Any further changes or modifications except the ones stated above are absolutely not recommended, because the amplifier is optimised so that it immediately reaches the required characteristics. Any modification would prevent that and would produce much worse results than the expected.

The amplifier should always be mounted on the aerial pole and connected to the aerial with the shortest possible cable, using coaxial relays to switch the aerial from receive to transmit. Its power supply should be fed through the coaxial

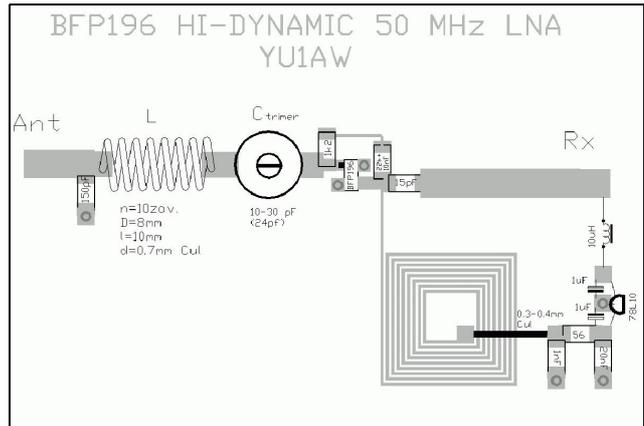


Fig 11: Component layout for 6m preamplifier.

cable that connects it to the receiver, using the adapter shown in Fig 8.

As expected, very good noise characteristics have been proved in practical use, which mainly satisfy every requirement for serious DX work. Only for EME work at 432 and 1296MHz you might try using lower noise value amplifiers, i.e. the GaAs-FET amplifiers [1-4], but in all other cases the amplifier satisfies even the most rigorous noise requirements. These amplifiers have shown exceptional linearity with IP3 values far exceeding 30dBm on all bands except at 1296MHz where it is 3-4dB lower.

As a comparison, Figs 9 and 10 show the performance of this amplifier and a common amplifier which uses an MGF1302 GaAs-FET. Both amplifier inputs have three signals of 7.1mV (-30dBm) to simulate “three strong stations on the band”. The graphs show what would be heard with an ideal receiver without its own IMD. With a real receiver, because of its possible IMD, things would look even worse! Before you

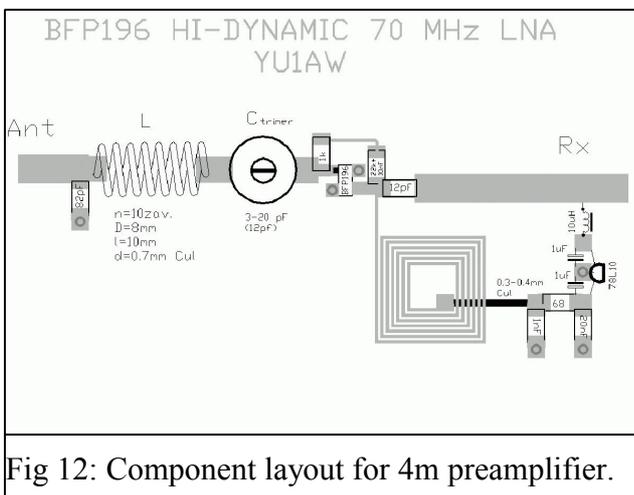


Fig 12: Component layout for 4m preamplifier.

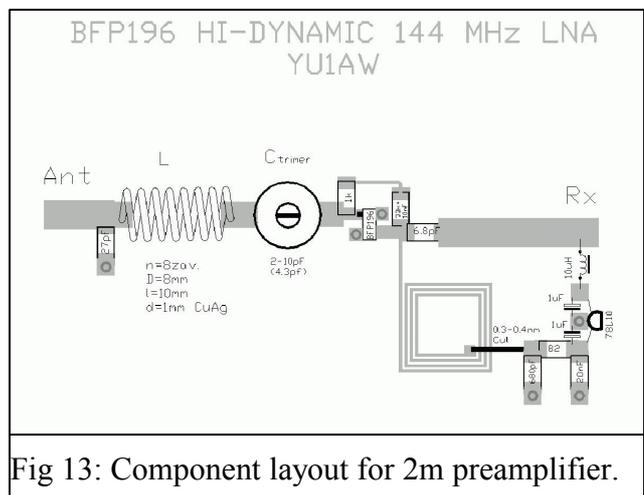


Fig 13: Component layout for 2m preamplifier.

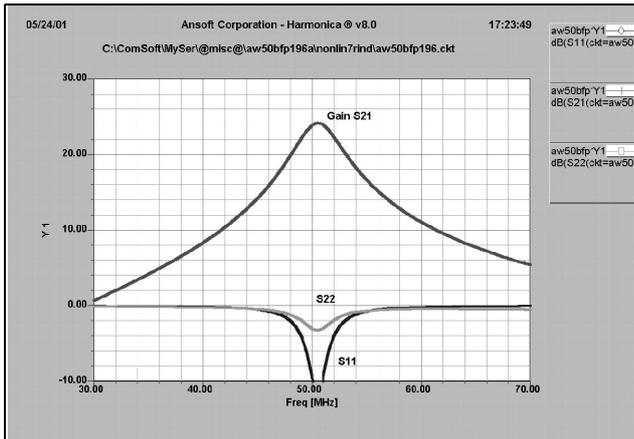


Fig 14: Amplification, input and output adjustment of the 6m preamplifier.

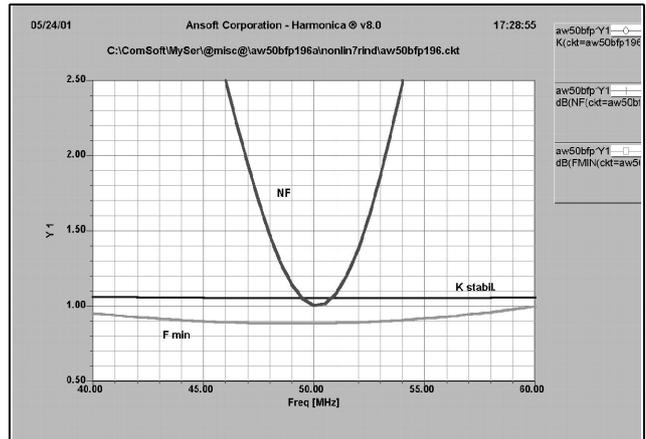


Fig 15: Noise figure, minimum noise and stability of the 6m preamplifier.

accuse someone of “band wasting” check with an input attenuator whether your receiver might actually be creating IMD due to a strong input signal! The amplifier using the BFP196 is superior to the one using the MGF1302. The difference in the IMD products appearing on the output of an ideal receiver was over 30dB! Of course, in both cases the amplifiers had approximately the same amplification.

The component layouts for the amplifiers are shown in Figs 11 - 13. The predicted performance of the 6m and 2m amplifiers are shown in Figs 14 - 21. The values shown have been simulated on a computer, and in real life proven on a sufficient number of built and measured amplifiers that they do not differ more than usual for this type of construction. Strict adherence to the guidelines given here will produce amplifiers with performance very close to those shown.

The final results achieved with these amplifiers

in real life conditions largely depend on the IMD characteristics of the receiver used. If it has weaker characteristics, then the results may even be worse in respect to IMD because when signals, amplified in the preamplifier, reach the input of a bad receiver they cause overload and the IMD in it and the results are poor. That is why the minimum necessary amplification is recommended between this amplifier and the first mixer in the receiver or the transverter in order to preserve as much dynamics of the whole receiving system as possible.

If IMD is apparent in the receiver it is recommended to put a variable attenuator between the amplifier and the receiver, define the lowest attenuation at which it disappears, replace it with a fix attenuation of the same value and work in that manner. This method is highly efficient because the IMD products are attenuated three times faster than the wanted signal, so that it is possible to weaken the products to the level

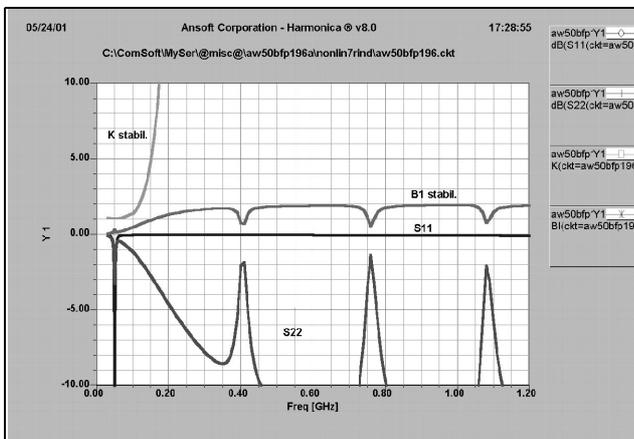


Fig 16: Stability factor and adjustment for the 6m preamplifier.

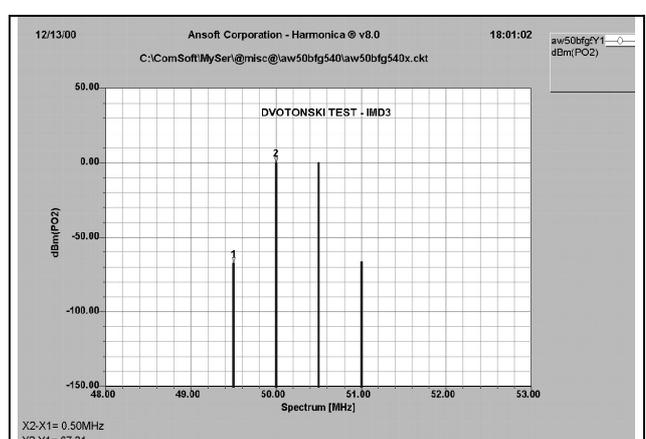


Fig 17: Two tone test and IMD products for the 6m preamplifier.

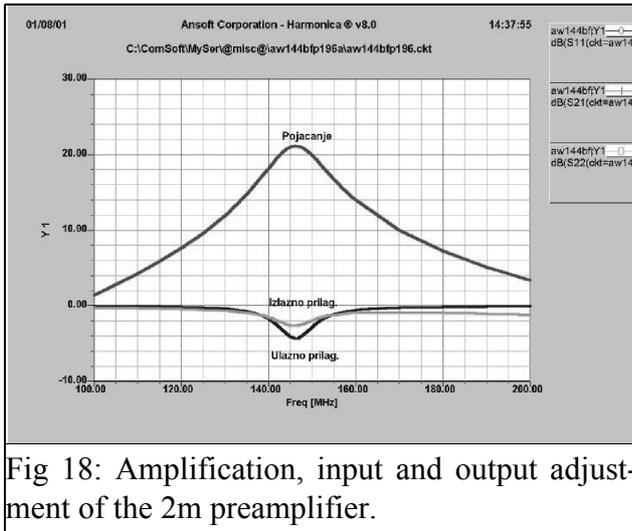


Fig 18: Amplification, input and output adjustment of the 2m preamplifier.

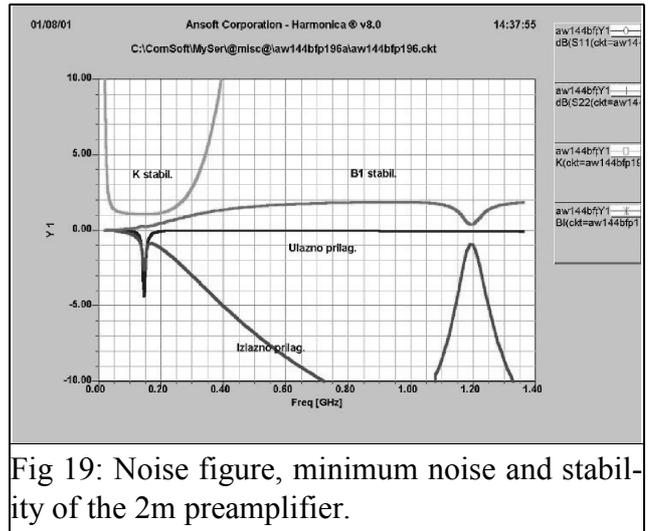


Fig 19: Noise figure, minimum noise and stability of the 2m preamplifier.

where they are not heard whilst preserving the useful signal with very little attenuation! Don't be afraid that you will not hear the desired signal, there is too much amplification as soon as IMD appears – feel free to lower it!

A miniature 100-500Ω trimmer potentiometer connected to the receiver input can be used in place of a variable attenuator. This can be built into the amplifier supply adaptor box as shown on Fig 8. This represents a very practical and rather elegant solution at least on lower bands. You can also use a variable 20dB attenuator used in CATV.

References

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[5] Web site: www.qsl.net/yu1aw/

[6] Author can be contacted on: dobricic@eunet.yu

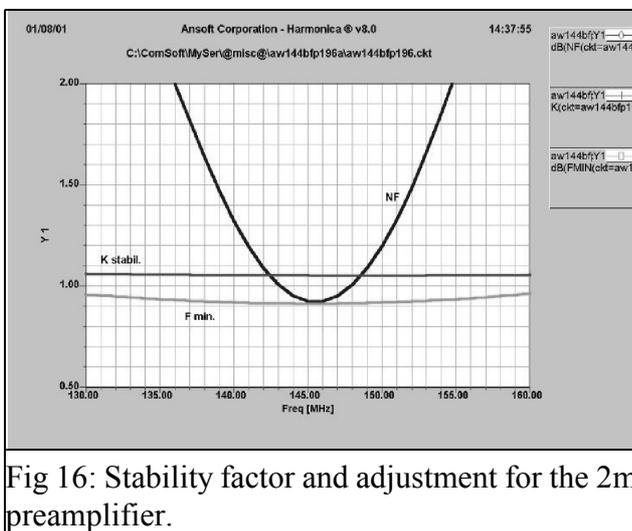


Fig 16: Stability factor and adjustment for the 2m preamplifier.

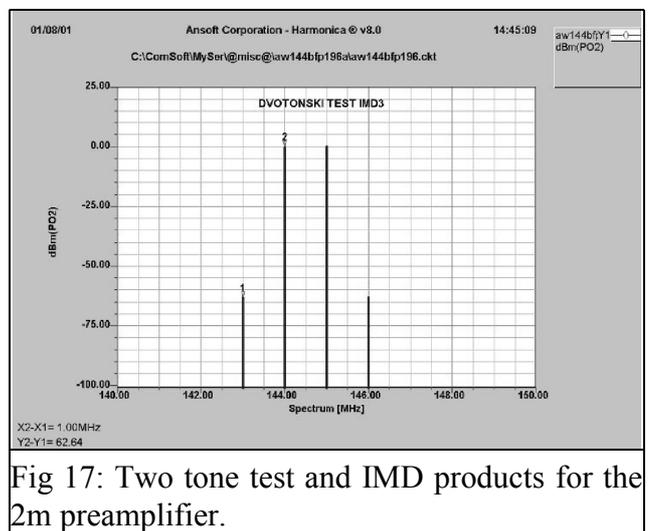


Fig 17: Two tone test and IMD products for the 2m preamplifier.