

COMPONENTS

Advantages of modern bipolar junction transistors over GaAs-FETs for low noise preamplifier applications on 3.4GHz

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Traditionally GaAs FETs have been used in the amateur radio community to build very low noise preamplifiers (LNAs) for frequencies in the 100MHz up to many GHz range. In order to achieve extremely low noise figures, it is still common practice to use relatively highly priced devices, that work up to much higher frequencies than what would be needed for a particular design.

While this has enabled the design of LNAs with noise figures of only 1dB and below, the designer always faces significant stability problems when using GaAs FETs for the LNA. This is because these FETs are able to oscillate at frequencies where bypassing and grounding becomes a challenge of its own. Also lumped elements like chip capacitors are well above their resonance frequency at the frequency of potential oscillation.

Another problem with using these extremely-high-frequency FETs is the very poor input and output match at the frequency of operation. That means the input, as well as the output, must be aggressively matched in order to get them close to 50Ohms. To make things even worse, the input impedance that gives the lowest possible noise figure is usually well away from 50Ohms, so if the input is tuned for minimum noise, the input match of the LNA circuit will be quite poor.

One more inconvenience with GaAs FETs used for LNAs is that most of them require a negative bias voltage, which is usually not available. So additional effort for implementing a voltage inverter must be spent.

While commercial manufacturers of RF communication equipment have widely switched to bipolar transistors for LNA applications, it seems that the amateur radio community has not yet followed this trend so far. Obviously there is a tendency to think that designers of commercial equipment mainly aim for low cost devices and don't care so much about the utmost performance. This may be true to a certain extent, but it does by no means indicate that bipolar transistors would not be an option even for demanding applications. While low cost is an absolute must for commercial designers today, it is also no disadvantage for the radio amateur if the components for homebrew projects are inexpensive. That becomes even more true if a number of devices is damaged during the design phase.

Let's have a look on the Infineon SiGe bipolar transistor BFP620 to understand what the advantages are. First of all it's cheap. Even at single pieces, purchased from an electronics mail order supplier, it is only 0.58 euro cents. And since it is less endangered by static discharge during handling than FETs are, fewer of them will probably be lost during construction. Secondly the BFP620 (as most of the other BJTs) is relatively well matched already. Over the entire frequency range from 100MHz to 6GHz the transducer gain (the device gain within a 50Ohm environment without matching) is only 1-2 dB less than the theoretically available or the theoretically stable gain with perfect matching. This basically eliminates the need for matching networks. Compared to GaAs FETs, this is very

convenient, as these have little to no gain at all, unless they are aggressively matched. Last, but not least important, the impedance for minimum noise figure of the BFP620 is very close to 50Ohm for frequencies from 1.5GHz-5GHz. That means that a preamplifier for 3.4GHz that is built using the BFP620 without any matching at the input, will achieve a noise figure only 0.1-0.2dB above the theoretical optimum. Since it is very likely that at least 0.1-0.2dB would be lost in the matching network due to ohmic losses, it is practically the best solution not to try any kind of input matching and connect the transistor just via a DC blocking capacitor to the antenna. Practically this would result in a noise figure of around 1.3dB for 3.4GHz. This may not be the method of choice for amateur radio EME (earth-moon-earth) applications, but for other applications it should really be fine. One should keep in mind that every tenth of a dB of cable loss between antenna and LNA adds directly to the noise figure. So everyone that has a few meters of cable between antenna and LNA should stop thinking about 0.1 or 0.2 dB of noise figure and mount the LNA directly to the antenna first.

It should also be noted that with the BFP620, a noise figure of around 1dB is achieved not only at frequencies much below the intended frequency range of the transistor, but right inside the specified frequency span. This means there is no need to use devices that have an extremely high transition frequency, just to achieve a good noise figure. If we consider the BFP620 again, this device is already unconditionally stable at frequencies above 5GHz. So oscillation at 10-20GHz is not a problem like it is for advanced GaAs FETs.

Of course where there is so much light, there is also some shadow. Due to its good match, even at low frequencies, the transducer gain peaks at more than 40dB at very low frequencies. With FETs on the other hand, it is possible to put the highest amplification at (or at least close to) the frequency of interest. Only at the frequencies where the (usually narrow banded) matching allows the signal to enter and leave the active device, the circuit will exhibit amplification. Excessive unwanted amplification at lower frequencies may or may not be a problem. If there was only the wanted signal in the air, one would probably not care about more amplification at other frequencies. Unfortunately there are many strong signals in the air today, like FM radio broadcast stations, TV broadcast stations, cell phone base stations etc. All these signals can and will produce intermodulation products within the receiver. The higher the amplification is for these signals, the more trouble they will cause in the receiver.

So, what is necessary to make a nice LNA for 3.4GHz out of a BFP620? First of all one has to make sure it does not oscillate. As mentioned this is a lot easier than for GaAs FETs. But if a high-Q narrow-band filter shall be put after the LNA, the transistor will see total reflection at all frequencies other than the pass band of the filter. This is always a very critical situation in terms of instability.

One could place a resistive attenuator between the LNA and the filter, but this would cost some of the gain that the LNA has produced just before. Other than GaAs FETs, the bipolar transistor provides the LNA designer with a nice possibility to solve this problem. Since the BFP620 is prone to instability especially at lower frequency where it exhibits a very high gain, it is very helpful to put a diplexer after the LNA that terminates everything below 2GHz into 50Ohms. This solution has the very nice side effect that it conquers the excessive gain at low frequencies and produces a rather flat frequency response. Simulations show that only by means of that diplexer and a very mild high pass filtering at the input, unconditional stability can be reached [1]. In order to minimize the number of external components, the diplexer at the output can be implemented as part of the bias network that is necessary anyhow.

At the input, a simple coupling capacitor to the antenna could be used, as there is no need for a matching network. In order to reduce intermodulation with the LNA and in order to gain the last bit of stability, it is sensible to put a band pass filter before the input. As every loss before the LNA adds directly to the noise figure, only filter topologies with extremely little loss are acceptable here. Since there is a need for feeding in the DC bias to the base of the transistor anyhow, a LC parallel configuration can be used that provides at least some amount of attenuation at outband frequencies, while causing almost no loss on the wanted signal at 3.4GHz.

[1] Dingfelder, H., "A Design Proposal for a 3.4GHz low noise preamplifier for amateur radio applications.", 2004