Simple Broadband Solid-State Power Amplifiers

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Recently, I was working on some VHF and UHF solid-state power amplifiers using LDMOS devices. These devices only take a few watts of drive to produce several hundred watts output, but they are rather sensitive to overdrive. I hate to tear apart a working station to test a new amplifier until I am certain it is working satisfactorily, so I prefer to do the testing on my workbench.

My broadband test amplifier only produces about one watt, fine for some preliminary tests, but not for full output from the SSPA. I needed something to produce 5 to 10 watts, and preferred not to build one for each band. Then I noticed a bag with some 2 GHz, 10 watt LDMOS FETs sitting on my workbench, where they had been since I acquired them at the last NEWS picnic.

Some years ago, when I was working professionally with power GaAsFETs, I saw a presentation[1] at a conference about broadband matched feedback amplifiers, and was inspired to build one – as I recall, it used a ½ watt 8 GHz GaAsFET and gave about 6 dB gain from VHF to around 3 GHz, with about ¼ watt power output. The beauty of the technique is that broadband impedance matching is provided by a single feedback resistor. The basic schematic, shown in Figure 1, is really simple.

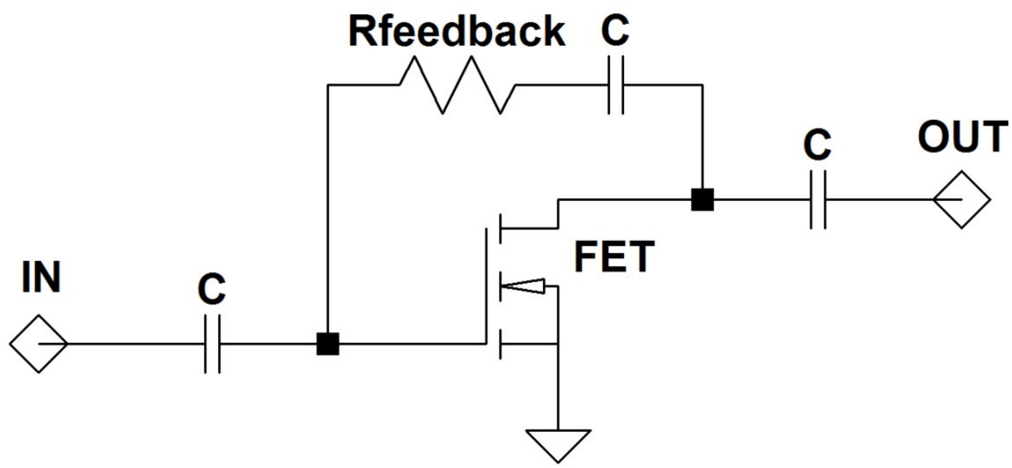

Figure 1- Schematic of FET Broadband Feedback Amplifier

I couldn't find the original conference Proceedings, but did find a more detailed paper[2] by the same author. This paper had the needed design equation for the feedback resistor, $\mathbf{R_{FB}}$:

$$R_{FB} = g_m Z_0^2$$

For the BLF2043F LDMOS FETs in the bag, the transconductance ($\mathbf{g_m}$) is 0.5 Siemens (or 500,000 µmho, in tube terms), so the needed feedback resistor is 1250 ohms. One consideration for the feedback amplifier is that the mimimum transconductance ($\mathbf{g_m}$) needed for a matched 50-ohm amplifier is 0.06 Siemens (or 60,000 µmho, in tube terms). This is a pretty big FET, so low-power FETs are not suitable, but power FETs are fine. I don't think any tube ever had a transconductance that high, so we can see why this technique was not popular with tubes.

Then the gain can be calculated:

$$Gain = 20log_{10}(g_m Z_0 - 1)$$

For the BLF2043F with $\mathbf{g_m} = 0.5$, the calculated gain is 27.6 dB.

Oldtimers may remember that for a triode $\boldsymbol{\mu = g_m R_p}$. Transconductance of a triode is much lower, but $\boldsymbol{Rp}$ was usually several thousand ohms.

Since this is a linear amplifier, we can simulate performance using S-parameters. I downloaded the S-parameters for the BLF2043F. Then I used Ansoft Designer SV (Student Version) to simulate the circuit of Figure 1 with the S-parameters for the device, starting with the calculated feedback resistance. The design equations above are a low-frequency approximation which does not account for the device capacitances, and it quickly became apparent that the approximation is inadequate. In the software, I varied the feedback resistance – a value of 160 ohms seemed to provide the best broadband performance, about 13 dB gain.

I found a small heatsink and a scrap of PC board with lines about the same width as the wide device leads – the line impedance is a bit lower than 50 ohms, but that shouldn't matter for short lines at these frequencies. The hardest part is drilling and tapping holes in the heatsink. Then the parts are soldered in – a common ¼ watt resistor and some chip capacitors. The capacitors are 1800 pf in parallel with 0.1 uF, since I wanted to be sure to provide a load at input and output at low frequencies to reduce the chance of oscillations. The feedback capacitors are standing on end, right on the device leads. The RF chokes are a few inches of fine wire wound around a small screwdriver.

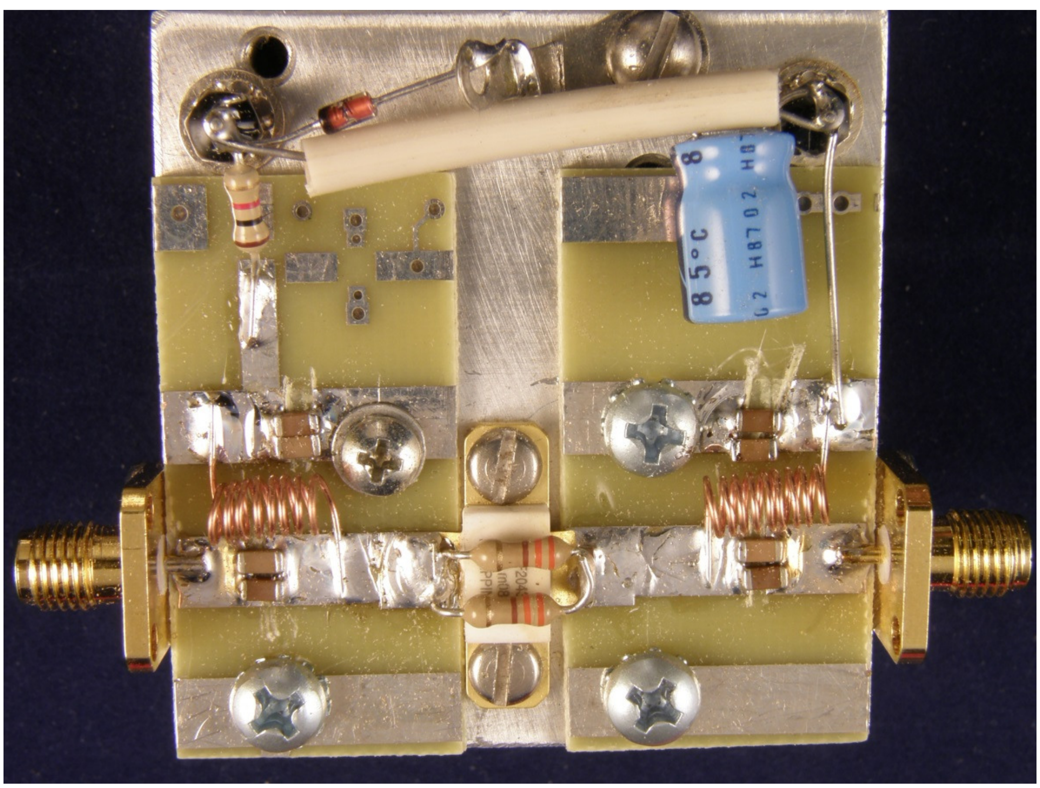

Figure 2 – BLF2043F Broadband Amplifier

The completed amplifier is shown in Figure 2. Note that the feedback resistor is two 330 ohm resistors in parallel, for 165 ohms. At 24 volts and about 200 mA idling current, gain is between 12 and 13 dB, pretty flat, from 36 to 490 MHz, with no tuning needed. Power output saturates around 8 or 9 watts at 144, 222, and 432 MHz, falling off to around 5 watts at 50 MHz. Reducing the voltage to 13 volts narrows the bandwidth and lowers the output power to 1 or 2 watts. Drain current increases to nearly an amp at full power, so the efficiency is mediocre.

The feedback resistor was initially a single 160 ohm resistor. The first time I drove up to full power, I smelled something burning – it was the feedback resistor. With 13 dB of feedback and 9 watts out, the resistor is dissipating nearly ½ watt, so it was cooking. The parallel resistors in Figure 2 cured the overheating.

Once the amplifier was working, I measured the gate bias voltage – about 5.1 volts on my first unit. A 5.1 volt zener diode is an easy solution, powered through a 2K resistor, which provides a few milliamps for the diode at 12 volts without overheating at 24 volts. Figure 3 adds all the bias components to the circuit.

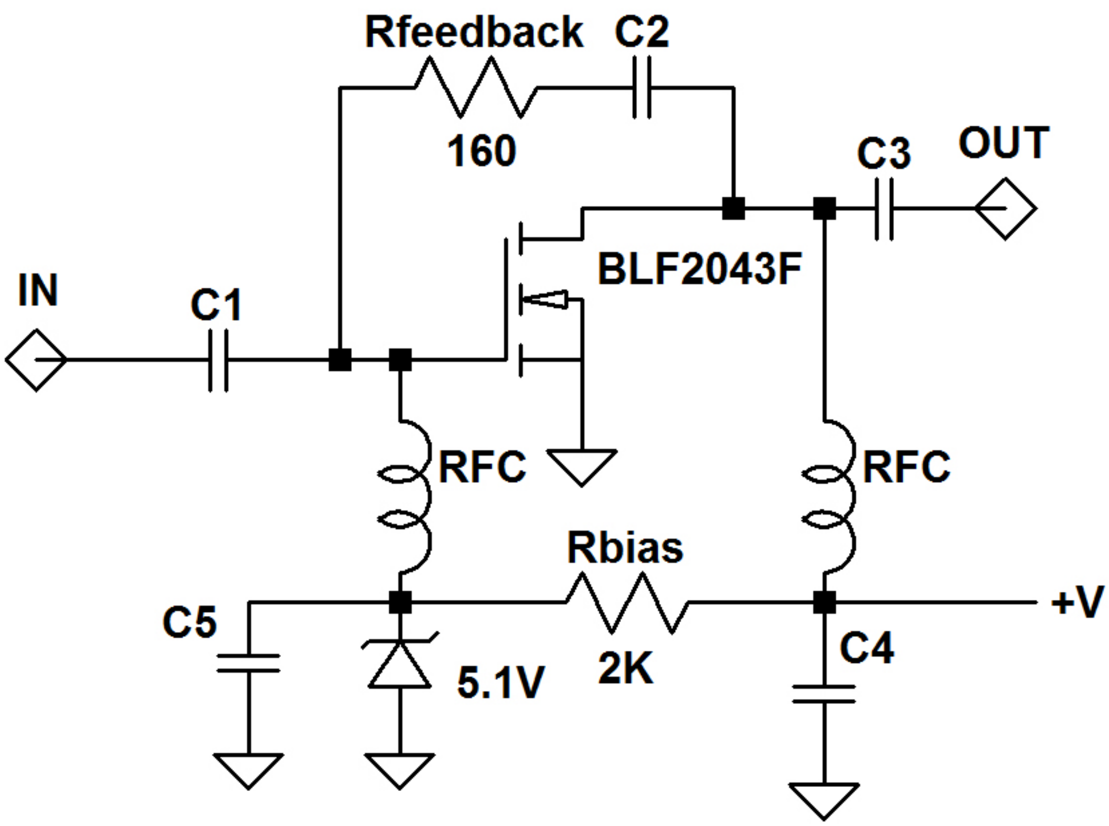

Figure 3- Schematic of BLF2043F Broadband Amplifier

I built a second copy of the amplifier, with similar performance. Figure 4 is a closeup view of this one at an angle, showing how the feedback resistors and capacitors are assembled. During testing, I noticed that there was still some gain left at 1296 MHz, perhaps 5 or 6 dB, so increased the drive and found that at least 1 watt output is available.

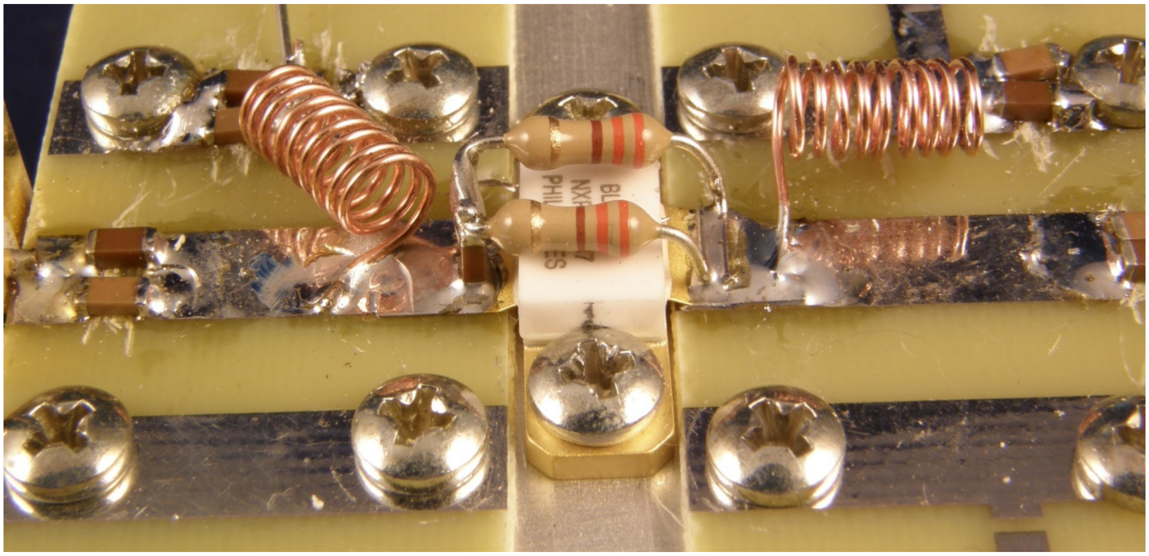

Figure 4 – Closeup of BLF2043F UHF Broadband Amplifier

This is a really simple way to build a broadband medium-power amplifier useful for testing. Since the maximum power output is proportional to the supply voltage, the voltage can be set to limit the output power and avoid overdriving an expensive SSPA.

For high-power amplifiers, using feedback for impedance matching would not produce full power – traditional impedance matching networks are needed. However, W6PQL uses feedback[3] in some of his kilowatt LDMOS amplifiers to reduce unwanted low-frequency gain.

Microwave Feedback Amplifiers

After I built the amplifier in Figure 2, I started thinking about higher frequencies, using some power GaAsFETs. Some digging in the archives unearthed the original GaAsFET amplifier, shown in Figure 4. I was amazed that it still works, 34 years later, with gain from 300 MHz up to 4.5 GHz.

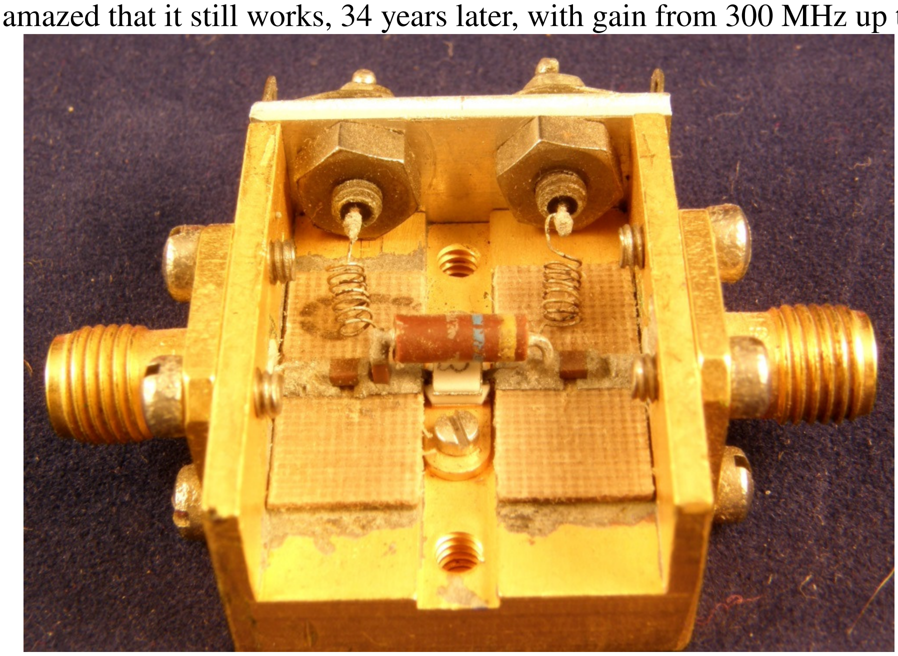

Figure 5 – Broadband feedback amplifier using ½ watt GaAsFET

The ½ watt GaAsFET has a the transconductance (g_m) of about 0.2 Siemens, so the calculated feedback resistor using the equation above is about 500 ohms. I had used 470 ohms. The calculated gain is 19 dB, but the actual gain is only about 6 dB.

I found a few 1-watt GaAsFETs in the junkbox that don't reach 10 GHz, so they might be useful for a broadband amplifier. The transconductance (g_m) of these devices should be roughly twice as much as the ½ watt device, or about 0.4 Siemens. Then the calculated feedback resistor would be 1000 ohms. However, the low gain of the ½ watt device and the simulations for the BLF2043F suggest that a lower resistance may provide better results. I guessed 220 ohms, and built the amplifier shown in Figure 6 using some ordinary FR-4 printed circuit boards with convenient 50-ohm transmission lines. For the feedback capacitor, I used 1000 pf in parallel with 0.1 uF, to help with low frequency stability. The input and output caps are 1000 pf.

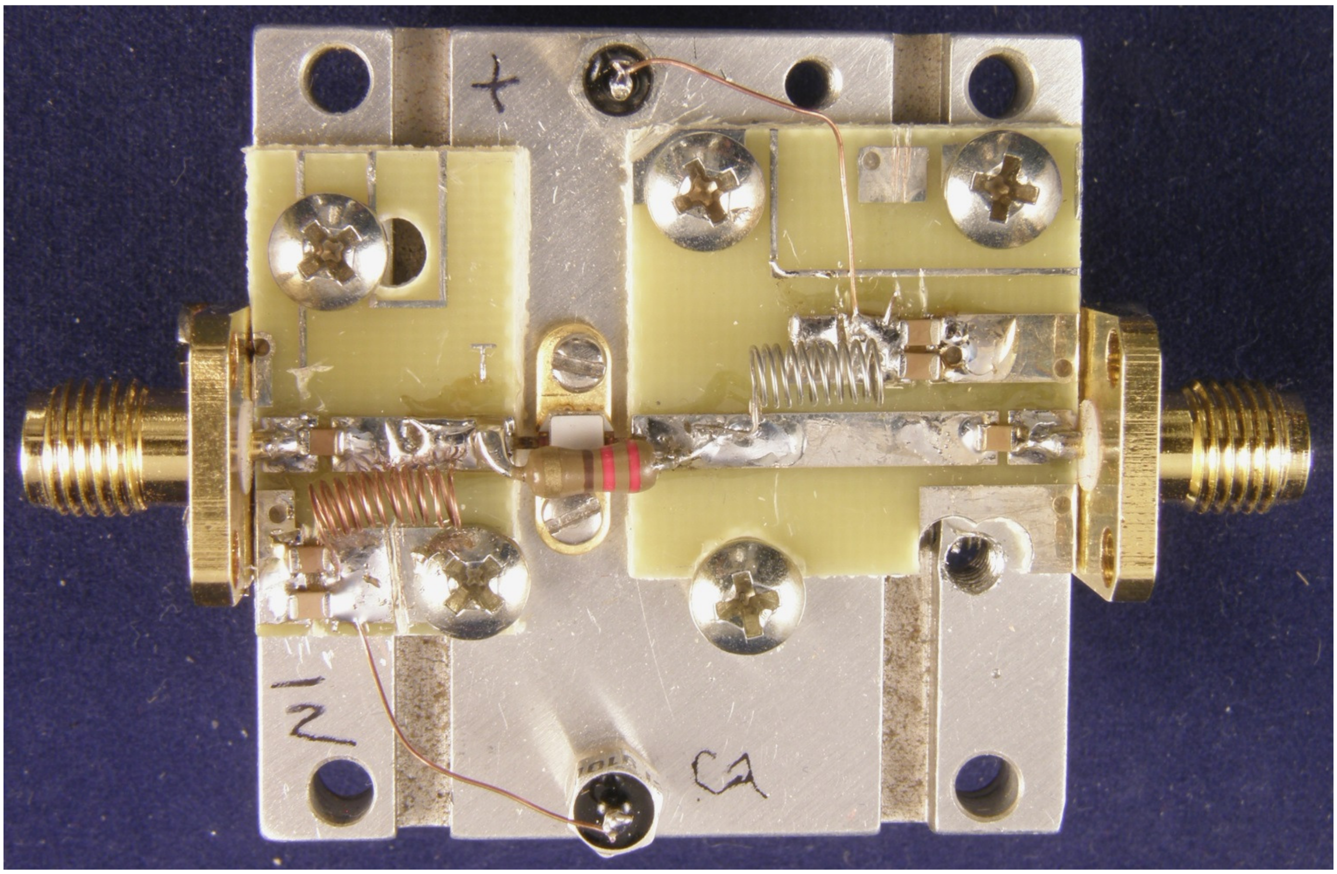

Figure 6 – Broadband feedback amplifier using ½ watt GaAsFET

This amplifier has good broadband performance, about 8 dB gain from about100 MHz to 2000 MHz, falling off to about 6 dB gain at 3.7 GHz, then dropping sharply. Maximum power output is about 300 milliwatts at 1.3, 2.3, and 3.45 GHz, and slightly more below 1 GHz. The schematic diagram for the GaAsFET amplifiers is similar to Figure 3, except for the gate bias, which is a negative voltage, -1 to -2 volts.

You may be wondering how these microwave amplifiers work with ordinary ¼ watt resistors providing the feedback – don't they have inductance? Yes, they do – the right amount of inductance can add a bit of peaking at the upper end of the frequency response, extending the bandwidth. I played with this in simulation, but didn't find any real improvement with the BLF2043F. To do it properly, all the circuit parasitics including the lead inductance of the FET must be included. For some applications, it might be preferable to optimize for a narrower frequency range or just one band; some of the optimization is probably best done on the physical amplifier using empirical techniques.

Summary

Broadband matched feedback amplifiers are simple to design and build, and offer predictable and useful performance. They are best suited for medium power applications, although feedback can be useful for improving stability in high-power amplifiers. Resistive feedback is not recommended for low-noise amplifiers, since the output noise is fed back to the input. There must be other feedback techniques for low noise amplifiers, since MMICs are available[4] that offer matched broadband performance with very low noise figures, but I don't know what they do inside.

When you see some microwave FETs at the next swap meet, they might be very useful.

References

1. Niclas, K., Wilser, W., Gold, R., Hitchens, W., "A 350MHz-14GHz GaAs MESFET amplifier using feedback," *1980 IEEE International Solid-State Circuits Conference Digest of Technical Papers*, IEEE, 1980, pp. 164-165.
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3. Jim Klitzing, W6PQL, "Solid State Kilowatt Amplifiers," *Proceedings of the 48th Conference of the Central States VHF Society*, ARRL, 2014, pp. 104-117.
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