High-Power GaAs FET Amplifiers: Push-Pull Versus Balanced Configurations

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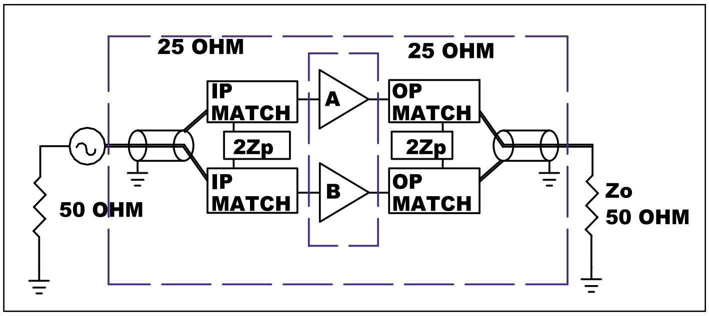
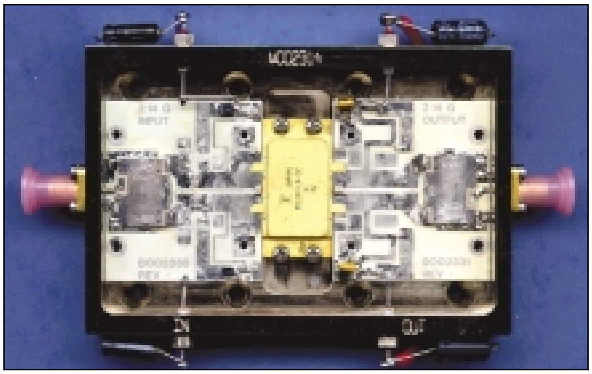
Most high-power microwave gallium arsenide (GaAs) field-effect transistor (FET) modules [2] up to L- and S-band (and soon up to C-band) consist of two independent devices without any internal transversal connection between them. Though often called push-pull amplifiers, the two devices can be combined in a variety of configurations created by external components, such as 180-degree splitter/combiners (ba-luns [3]); 3 dB quadrature couplers, such as branch line or Lange couplers; or in-phase couplers, such as Wilkinsons.



▲ **Figure 1. Conceptual block diagram of the microwave push-pull amplifier.**

Push-pull [2] and balanced [4] configurations are both used for high-power GaAs FET amplifier designs for relatively narrow band commercial applications from UHF to S-band. In the near future, these devices will be available at higher frequencies.

The question is whether push-pull amplifiers are better suited for these applications than balanced ones. This article compares the push-pull and balanced configurations for amplifiers using dual GaAs push-pull devices for commercial applications with less than 1 octave bandwidth.



▲ **Figure 2. Push-pull amplifier as built and tuned.**

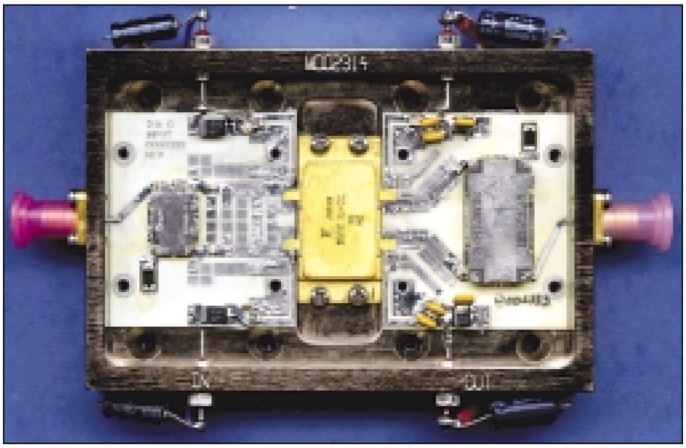
Push-pull amplifier

A push-pull amplifier (see Figures 1 and 2) consists of an input 0 to 180-degree power splitter driving two identical devices in antiphase and a 0 to 180-degree output power combiner adding the output power of the two devices in the amplifier load. The splitter and combiner are baluns [3] (BALanced UNbalanced). Baluns transform a balanced system that is symmetrical with respect to ground to an unbalanced system with one side grounded.

Note that the push-pull amplifier contains two independent devices each amplifying an individual signal of half the total power.

Advantages of the push-pull amplifier:

- Four times higher device impedance [5] (Z_{in} Gate-to-Gate and Z_{out} Drain-to-Drain) compared to single-ended device impedances with



▲ **Figure 3. Balanced amplifier as built and tuned.**

the same output power. Thus it is easier to match.
- Virtual ground [5], which can be used for more compact and simpler matching structures.
- Cancellation of even products and harmonics, such as F2-F1, 2F1, 2F2, F1 + F2...

Disadvantages of the push-pull amplifier:
- Poor input and output external match because the baluns used for push-pull amplifiers do not eliminate the input and output power reflected by the device.
- With conventional baluns, isolation between the two sides of the part is theoretically only 6 dB; this poor interdevice isolation can cause instability problems.
- Use of baluns: coaxial baluns are simple to make for laboratory use but in production they have high labor cost. Surface-mount technology (SMT) baluns are available but add cost and tend to be larger than equivalent quadrature couplers.

Balanced amplifier

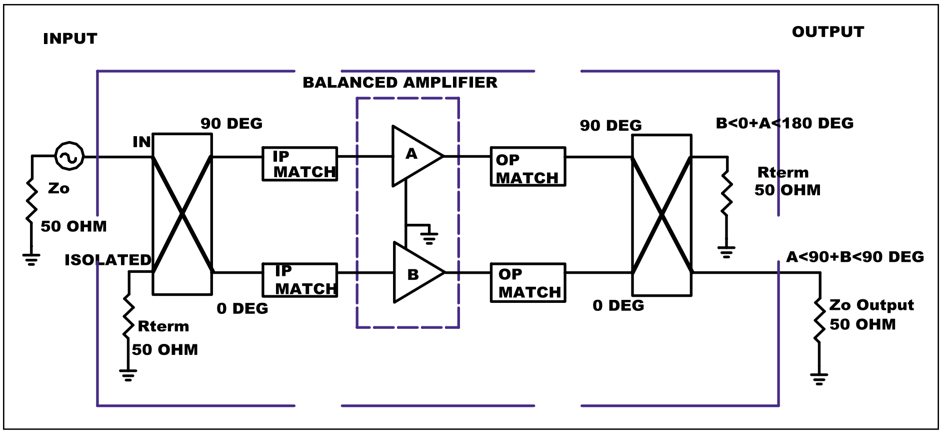
The balanced amplifier [3, 6] (see Figures 3 and 4) uses a splitter at the input and a combiner at the output, with a 90-degree phase difference between the coupled and through ports. The fourth port of the splitter/combiner must be terminated with a good 50-ohm load (for a 50-ohm system impedance). This resistor must reliably dissipate the reflected power by the input circuit of the devices, the reflected power from the amplifier load and the power due to the unbalance between the two sides of the amplifier for the combiner. As power goes up, the power rating and size of these resistors must increase. The load of the splitter can be relatively small compared to the load of the combiner.

The input signal is split at 0 and 90 degrees, amplified, then added in the load by the 90-degree combiner. Due to the phase shift, the output voltage of the two signals in the load of the isolated port of the combiner are cancelled and the load connected at the load combiner port sees the sum of these two signals.

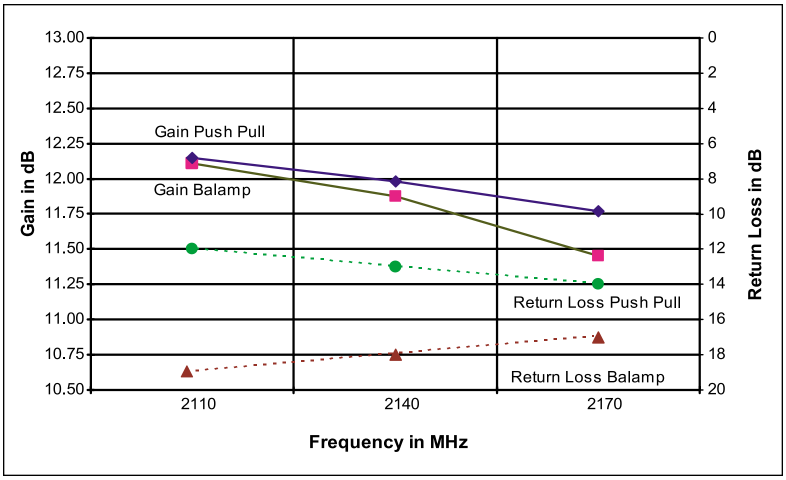
Advantages of the balanced amplifier configuration:
- Good isolation between the two halves of the device. This improves amplifier stability within the bandwidth of the coupler.
- Good input and output external match, since the reflected power is absorbed by the 50-ohm load in the isolated coupler port. This gives a constant well-defined load to the driver stage, improving amplifier stability and driver circuit power flatness versus frequency.
- Cancellation in the load of third-order products and harmonics such as 2F1+F2, 2F2+F1, 3F1, 3F2.... and attenuation by 3 dB of second-order products such as F1-F2, F1+f2, 2F1, 2F2...
- Easy to design and integrate within a printed or SMT 3 dB quadrature coupler.

Disadvantages of the balanced amplifier configuration:
- Requires the use of a 50-ohm load in the decoupled port of the input and output couplers. This is an extra part that must be purchased and installed. High-power resistors can be expensive and require proper heat sinking.
- Couplers must be used that require either design effort (this type of coupler is well documented and easy to design) for printed quadrature couplers or purchased and installed.
- No virtual ground. This leads to a generally less compact tuning structure.

Push-pull versus balanced:
- Single tone performance should be equivalent. The external elements matching circuits and the splitters and combiners have similar loss. Note that both styles have different advantages in multi-octave amplifiers that do



▲ **Figure 4. Conceptual block diagram of the microwave balanced amplifier.**

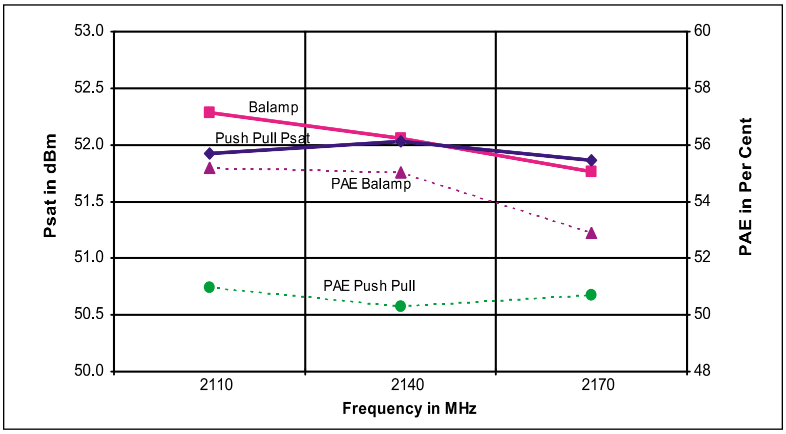


▲ **Figure 5. Gain and return loss versus frequency for average of five devices in each configuration.**

- Linearity is the same for amplifiers with less than one octave in bandwidth. Matching circuits filter the even products and harmonics for the push-pull configuration and the products and harmonics are attenuated or cancelled by the balanced configuration before they reach the output combiner. The output balun and quadrature coupler have limited bandwidth and cannot cancel products and harmonics that are out of the passband.
- The push-pull configuration has an impedance transformation ratio advantage of two for conventional baluns. This can make the design easier, depending on the impedance to be matched.
- Balanced amplifiers have a significant external match advantage.
- Balanced amplifiers are more stable due to good isolation between the two device sides.

not come into play in this discussion of narrow-band (5 to 10 percent) commercial amplifiers. Because even products and harmonics are out of the passband of the matching circuits and the baluns, the cancellation of these products does not exist. Consequently, for narrow-band applications, this advantage of the push-pull configuration is not realized.

- The virtual ground present for the push-pull configuration can be used with lumped tuning capacitors between the two sides for simpler tuning.
- Both configurations can be tuned using open stubs, preferred in production to lumped capacitors for their lower cost, lower loss, easy modeling and better power handling capability.



▲ **Figure 6. Saturated power and PAE versus frequency for balanced and push-pull amplifier configurations.**

After reviewing the advantages and disadvantages of push-pull versus balanced configurations, the amplifier designer may select the best configuration for his application.

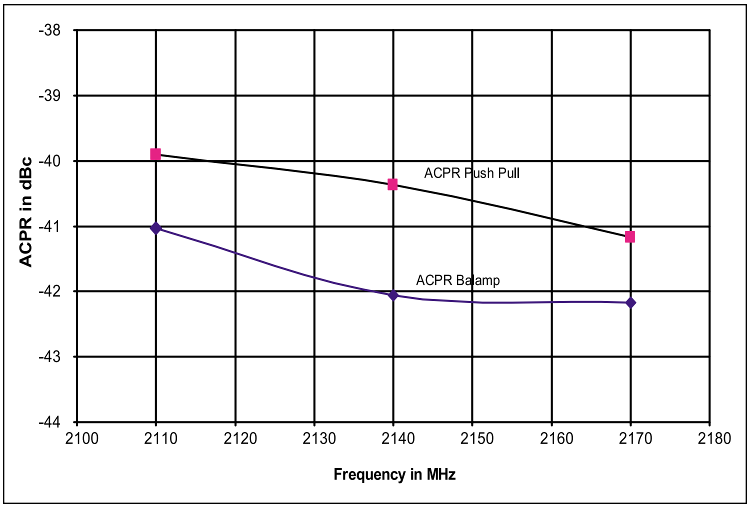
To illustrate, two amplifier designs were created at 2.11 to 2.17 GHz, using the GaAs FET device FLL1500IU-2C(1), a Fujitsu 150-watt internally partially matched device. Both balanced and push-pull designs were realized. Five devices were selected from three lots and tested in each amplifier type without changing the amplifier tuning. The measured results from testing the same five devices in each amplifier are summarized in Table 1.

Test data analysis

Figures 5, 6 and 7 show that the two configu-

Parameter/Condition for Vds = 12 volts, Idsq = 4A	Push-Pull Data	Balanced Data
Linear Gain (GL)	12 dB	11.8 dB
Input Return Loss (RL)	13.4 dB	20.2 dB
Saturated Output Power (Psat)	51.9 dBm	52.0 dBm
Power-Added Efficiency at Psat (PAE or Nadd)	51 percent	54 percent
Third-Order Intermodulation Ratio for 43 dBm Total Power out (IMD3)	–36.4 dBc	–38.5 dBc
Adjacent Channel Power Ratio (ACPR) for 3GPP (3.8 MHz) Test Model 1, 64 DPCH CDMA modulation at 43 dBm Pout	–40.5 dBc	–41.8 dBc

▲ **Table 1. Push-pull versus balanced amplifier data. The data for GL, RL, Psat, PAE and ACPR are average for five samples from three lots tested at three frequencies in each amplifier without retuning. IMD3 data is the average of five samples at one frequency in each fixture.**



▲ **Figure 7. Adjacent channel power ratio versus frequency for P_{out} = 43 dBm for both the balanced and push-pull amplifier configurations.**

rations have similar (within 0.1 to 0.2 dB) linear gain (GL) and Psat. The linearity performance is slightly better (2.1 dBc for IMD3 and 1.3 dBc for adjacent-channel power ratio (ACPR)) for the balanced configuration. The balanced amplifier exhibits a better power-added efficiency (PAE) by 3.7 percentage points.

This unexpected difference can be misleading. Theoretically, the two types should have the same PAE or linearity. However, this may be explained by the fact that two external matching circuits present to the device the same impedances at the fundamental frequency and different ones for the harmonics. This difference of impedances for harmonics may affect the linearity and efficiency.

The input return loss data shows the superiority of the balanced configuration (6.8 dB better input return loss) concerning the external match.

Conclusion

This article discussed the relative performance of push-pull and balanced amplifiers. A sample 150-watt amplifier of each type was constructed and tested. The performance verified what was anticipated in theory: the basic performance parameters are similar, with the exception of the external match, which is better for the balanced configuration. ■

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