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

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High-Power GaAs FET Amplifiers: Push-Pull versus Balanced Configurations
Example: WCDMA (2.11-2.17 GHz), 150W Amplifiers

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Abstract

Various methods of combining high power "push-pull" devices are often possible. Two methods, push-pull and balanced configurations, are theoretically discussed. A practical example with a push-pull and a balanced amplifier using the same 150 W, S-band GaAs device(1) is reported and amplifier data are compared and analyzed.

Introduction

- Most high power microwave GaAs FET devices(2) up to L- and S-band and soon up to C-band consist of two independent sides without any internal transversal connection between the two sides. Though often called push-pull devices, the two sides can be combined in a variety of configurations created by external components such as 180-degree splitters/combiner (baluns(3)), 3 dB quadrature couplers (like branch line or Lange couplers), in phase couplers (like Wilkinson couplers), etc.
- Push-pull(2) and balanced(4) configurations are both intensively used for High-Power GaAs FET Amplifier designs using push-pull devices for relatively narrow band commercial applications from UHF to S-band. In near future this type of device will be available at higher frequencies.
- The question has arisen as to whether or not push-pull amplifiers have more advantages for these applications than balanced ones.
- The goal of this presentation is to compare the push-pull configuration to the balanced one for amplifiers using GaAs push-pull devices for commercial applications with less than one octave bandwidth.

Discussion

Push-Pull Amplifier

Definition:
A push-pull amplifier consists of an input 0-180-degree power splitter driving two identical devices in antiphase and a 0-180-degree output power combiner adding the output power of the two devices in the amplifier load. This type of splitter and combiner, which are the key elements of the amplifier, are called baluns(3) (BALanced UNbalanced). They transform a balanced system that is symmetrical with respect to ground to an unbalanced system with one side grounded.
Note that the microwave push-pull amplifier is two independent devices each amplifying an individual signal of half the total power.
Figure 1 shows the conceptual block diagram of a push-pull amplifier.

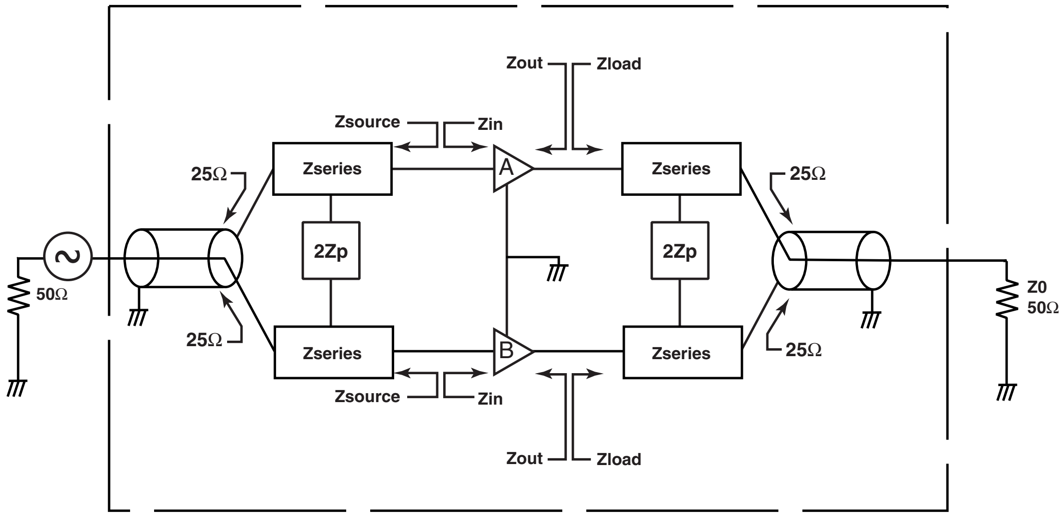

Figure 1: Conceptual Block Diagram of Microwave Push-Pull Amplifier

Advantages of real push-pull amplifier:

1. Four times higher device impedance(5) (Zin Gate-to-Gate & Zout Drain-to-Drain) in comparison of a single-ended device impedances with the same output power. Thus it is easier to match.
2. Virtual ground(5), which can be used for more compact and simpler matching structures.
3. Cancellation of even products and harmonics, such as F2-F1, 2F1, 2F2, F1 + F2, etc.

Disadvantages of the push-pull Amplifier:

1. Poor input and output external match due to the fact that the baluns used for push-pull amplifiers do not eliminate the input and output power reflected by the device.
2. With conventional baluns, isolation between the two sides of the part is theoretically only 6dB; this poor interdevice isolation can cause instability problems.
3. Use of baluns: manually made coaxial baluns are simple to make for lab use but in production they require labor that makes mass production difficult. SMT baluns are available but add cost and tend to occupy more real estate than equivalent quadrature couplers.

Balanced Amplifier

Definition:
A traditional amplifier configuration at high microwave frequencies is the balanced amplifier[3 & 6]. It uses a splitter at the input and a combiner at the output with a 90-degree phase difference between the coupler and transmit ports of these directional couplers. The fourth port of the splitter/combiner must be terminated with a good 50-ohm load (for a 50 ohm system impedance) to maintain the performance of these directional couplers. This resistor must be able to reliably dissipate the reflected power by the input circuit of the devices for the splitter, the reflected power by 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 also increase. The load of the splitter can be relatively small in comparison with the load of the combiner.

The input signal is split at 0 and 90-degree, 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, while the load connected at the other combiner port sees the sum of these two signals. See Figure 2 for a conceptual block diagram.

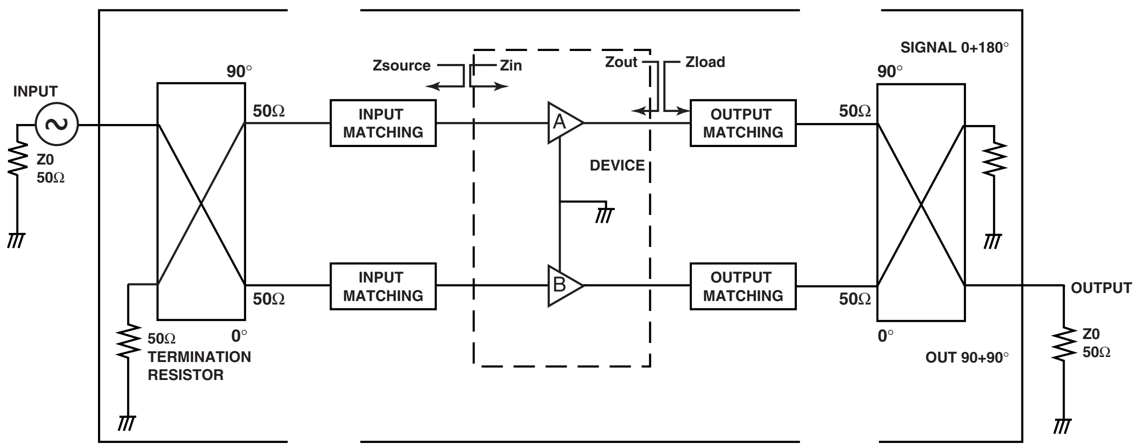

Figure 2: Conceptual Block Diagram of Microwave Balanced Amplifier

Real Balanced Amplifier Configuration: Advantages

1. Good isolation between the two halves of the device. This improves amplifier stability in the bandwidth of the coupler.
2. Good input and output external match, since the reflected power is absorbed by the 50 ohm-load in the decoupled coupler port. This gives a constant well defined load to the driver stage, improving amplifier stability and the level of driver circuit power available.
3. Cancellation in the load of products and harmonics like 2F1+F2, 2F2+F1, 3F1, 3F2…. and attenuation by 3 dB of products like F1-F2, F1+f2, 2F1, 2F2…
4. Easy to design and integrate a printed or SMT 3 dB quadrature coupler.

Balanced Amplifier Configuration: Disadvantages

1. 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.
2. Couplers must be used, requiring either design effort (this type of couplers are well documented and easy to design) for printed quadrature couplers or purchased (SMT) components to be installed.
3. No virtual ground. This leads to a generally less compact tuning structure.

Comparison Push-Pull vs Balanced

1. 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 not come into play in this discussion of narrow band (5-10 %) commercial amplifiers. Due to the fact that even products and harmonics are out of the pass band of the matching circuits (internal and external) and the baluns, the cancellation of these products doesn't exist and consequently for narrow band applications the push-pull configuration is not more efficient.
2. Linearity is the same for amplifiers with less than an octave in bandwidth. Matching circuits (internal and external) are filtering the even products and harmonics for the push-pull configuration and the products and harmonics attenuated or cancelled by the balanced configuration before they reach the output combiner. The output balun and quadrature coupler have limited band and in general cannot cancel these products and harmonics that are out of their pass band.
3. Push-pull configuration has an impedance transformation ratio advantage of two for conventional baluns. This can make design easier, depending on the impedance to be matched.
4. Balanced amplifiers have a significant external match advantage.
5. Balanced amplifiers are more stable due to the good isolation between the two device sides.
6. The virtual ground present for the push-pull configuration can be used to advantage with lumped tuning capacitors between the two sides to make for fast tuning.
7. Both configurations can be tuned using open stubs, which are preferred in production to lumped capacitors for their lower cost (free and no assembly), lower loss, ease to model and their power handling capability.

After having reviewed the advantages and disadvantages of the two configurations, it should be easy for the amplifier designer to select the best configuration for his application. This choice may also depend on his background.

Example

In order to verify the above theoretical discussion, two amplifier designs were created at 2.11-2.17 GHz using the GaAs FET device FLL1500IU-2C(1), a Fujitsu 150 W internally partially matched device. Both balanced and push-pull designs were realized. Five devices were selected from 3 lots and tested in each amplifier style without changing the amplifier tuning. The measured results from testing the same 5 devices in each amplifier are summarized in Table I.

Table 1: Push-Pull vs Balanced Amplifier Data

Parameter/Condition for Vds = 12V, Idsq = 4A	Push-Pull Data*	Balanced Data*
Linear Gain (G_L)	12dB	11.8dB
Input Return Loss (R_L)	13.4dB	20.2dB
Saturated Output Power (psat)	51.9dBm	52.0dBm
Power-added Efficiency at Psat (PAE or Nadd)	51%	54%
3rd Order Intermodulation Ratio for 43 dBm Total Power out (IMD3)	-36.4dBc	-38.5dBc
Adjacent Channel Power Ratio (ACPR) for 3GPP (3.84MHz) Test Model 1, 64 DPCH CDMA modulation at 43dBm Pout	-40.5dBc	-41.8dBc

*The data for G_L, R_L, Psat, PAE and ACPR are averages for 5 samples from 3 lots tested at 3 frequencies in each amplifier without returning. IMD3 data is the average of 5 samples at one frequency in each fixture.

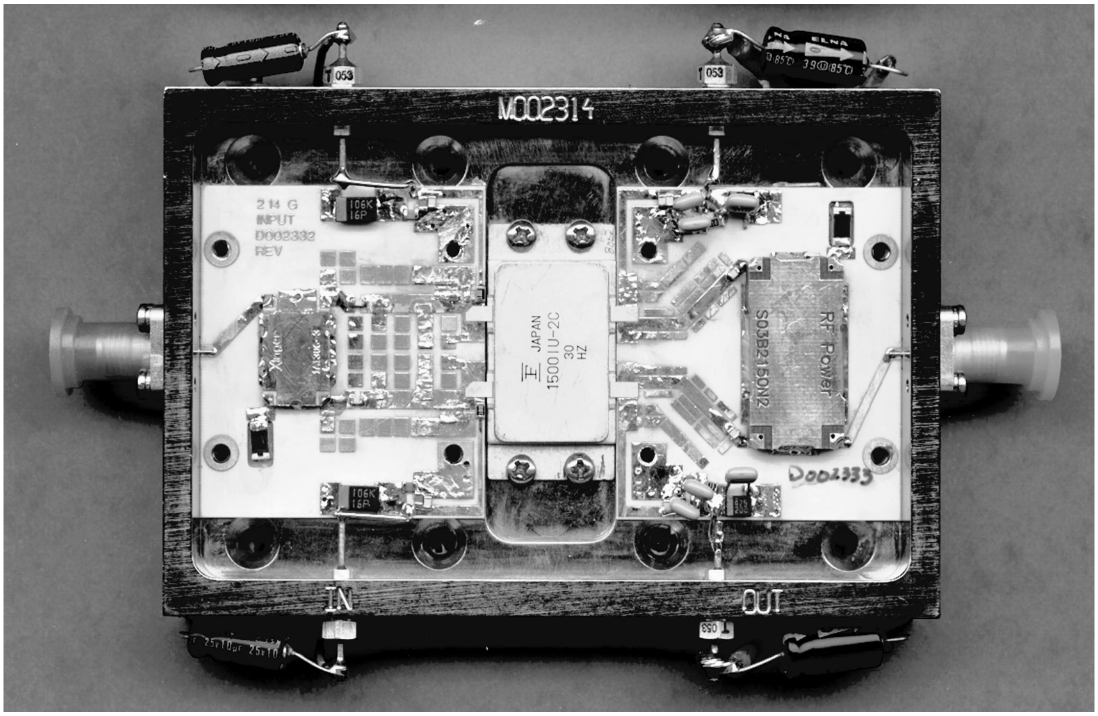

Figure 3: Balanced Amplifier as built and tuned

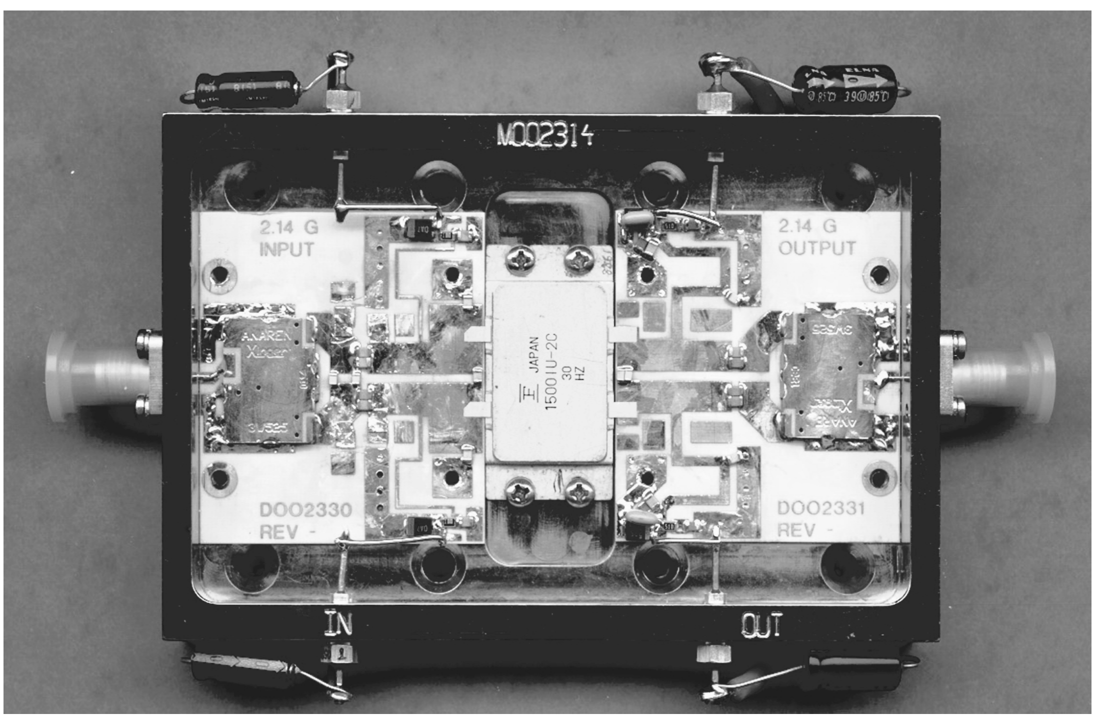

Figure 4: Push-Pull Amplifier as built and tuned

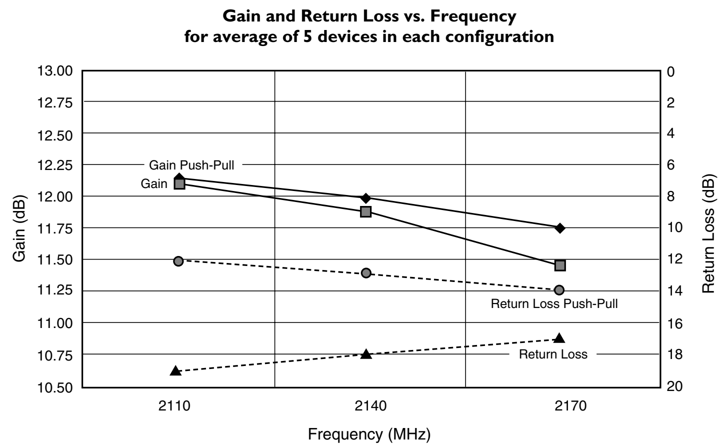

Figure 5: Plot of Linear Gain(GL) and Return Loss for the two configurations

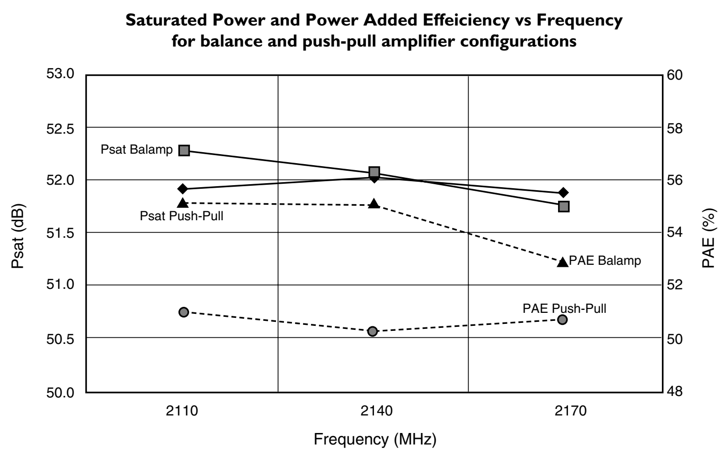

Figure 6: Plot of Saturated Power and Power Added Efficiency for the two

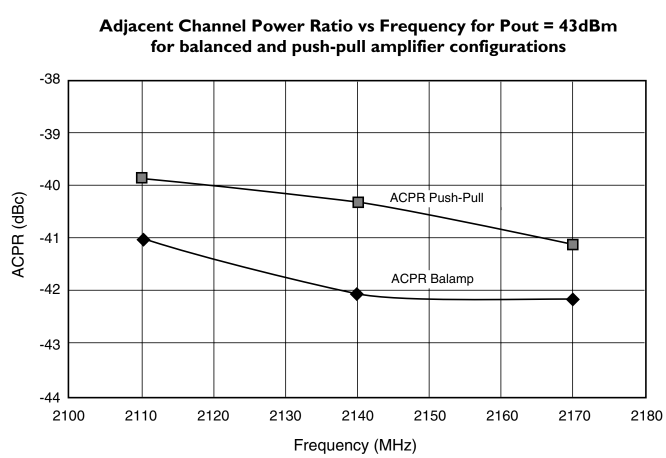

Figure 7: Plot of Saturated Power and Power Added Efficiency for the two

Test Data Analysis

The above data show that the two configurations have almost exactly (within 0.1 to 0.2 dB) the same GL and Psat. The linearity performance is very close with a little advantage (2.1 dBc for IMD3 and 1.3 dBc for ACPR) for the balanced configuration. The balanced amplifier exhibits a better PAE by 3.7 percentage points. This difference, which is more than expected, can be misleading. Theoretically there is no expected difference in PAE or linearity between the two amplifiers. However the explanation may be that the 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 make a difference for linearity and efficiency, which are a function of these impedances.

Thus the basic amplifier performance is essentially the same.

The Input Return Loss data show the superiority of the balanced configuration (6.8 dB better input return loss) concerning the external match.

Conclusion

The relative performance of push-pull and balanced amplifiers has been discussed and their relative performance predicted. A sample 150 W amplifier of each type has been constructed and tested. The performance verified the theoretical discussion that the basic performance parameters would be similar with the exception of the external match that is better for the balanced configuration.

References

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