A 40W Push-Pull Power Amplifier for High Efficiency, Decade Bandwidth Applications at Microwave Frequencies

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***Abstract* — A high-efficiency push-pull power amplifier has been designed and measured across a bandwidth of 250MHz to 3.1GHz. The output power was 46dBm with a drain efficiency of above 45% between 700MHz and 2GHz, with a minimum output power of 43dBm across the entire band. In addition, a minimum of 60% drain efficiency and 11dB transducer gain was measured between 350MHz and 1GHz. The design was realized using a coaxial cable transmission line balun, which provides a broadband 2:1 impedance transformation ratio and reduces the need for bandwidth-limiting conventional matching. The combination of output power, bandwidth and efficiency are believed to be the best reported to date at these frequencies.**

***Index Terms* — Balun, high efficiency, microwave amplifiers, power amplifiers, push-pull, wideband.**

I. Introduction

Designing a power amplifier (PA) to deliver high efficiency over a bandwidth of greater than an octave is a significant challenge at microwave frequencies, and the challenge increases as the power level is raised. The conventional approach for designing broadband microwave power amplifiers has been to use a single device biased in Class A, usually with some feedback, however this approach generally yields low efficiency amplifiers. At higher frequencies a distributed architecture is frequently used, but this is also not a high efficiency approach. Previous works on push-pull power amplifiers have either presented wide bandwidths but modest efficiencies and output powers [1] or high power and efficiency over limited bandwidths [2].

A high-power, push-pull PA is presented in [3]. Using ferrite-based magnetically coupled transformers, high efficiency and output power is maintained across a bandwidth of 100MHz to 1GHz. However, attempts to extend this performance above 1GHz will be limited by the ferrite materials currently available for constructing transformers.

For applications above 1GHz, it is necessary to use an alternative design of balun that uses the properties of a transmission line rather than magnetic coupling.

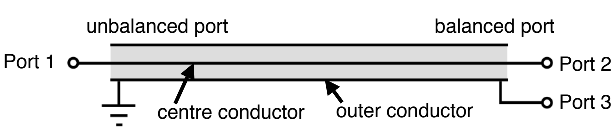

Fig. 1. Simple schematic of a coaxial cable transmission line balun.

Such a balun may be made from a straight piece of coaxial cable mounted above a ground plane, where the length of the cable is chosen to be less than a half wavelength at the specified upper frequency limit. This structure has a wide useable bandwidth, which can be further extended as described in [4], albeit with increased insertion loss.

In this paper, we describe the design and manufacture of a push-pull power amplifier output stage using a ferrite-less coaxial cable balun that outputs 40W (46dBm) output power at greater than 45% drain efficiency between 700MHz and 2GHz. Furthermore, the amplifier output power is above 43dBm between 250MHz and 3.1GHz, a bandwidth greater than a decade. These results clearly demonstrate the advantages of the push-pull configuration in designing high efficiency PAs for broadband microwave applications.

II. Advantages of the Push-Pull Configuration

Single-ended power amplifiers designed to operate over significant bandwidths tend to use transistors biased in Class A with filter-based matching networks, the design of which is well documented [5]. As the required transformation ratio between the 50Ω system impedance and the optimum device impedance increases, the Q factor of the matching network also increases and hence the bandwidth is reduced. This is particularly problematic for higher power devices, where the output impedance of a device can be of the order of one Ohm or less, and a high transformation ratio is required.

The push-pull configuration, where two transistors are operated 180° out of phase, greatly alleviates the limitations of conventional matching networks. The simple transmission line balun of Fig. 1 presents an odd-mode impedance of approximately 25Ω to each half of the balanced output, as shown in Fig. 2. The impedance presented to Port 3 of the balanced output decreases at low frequencies as the length of coaxial cable ceases to be a substantial fraction of a wavelength. At higher frequencies, the Port 3 impedance tends towards a short circuit due to the half-wavelength resonance.

The 2:1 transformation ratio is maintained over the operational bandwidth of the balun. It can therefore be reasonably stipulated that in an equal power comparison, using identical device types, the push-pull configuration not only offers a 4:1 benefit in matching Q-factor, but also achieves this using a structure that is inherently much broader band than filter-based matching networks.

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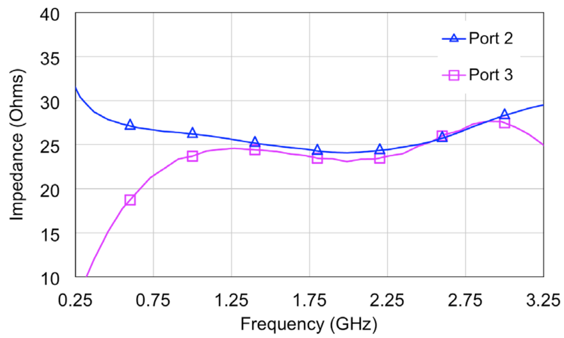

Fig. 2. Measured odd-mode impedance presented to each half of the balanced output port of a coaxial cable transmission line balun.

Due to its transmission line properties, the balun will not support any even-mode current component and thus presents an open circuit termination to signals at the even harmonic frequencies. This represents an important difference between high frequency push-pull design using transmission line baluns, and low frequency designs based on magnetically coupled transformers, since in the latter case the even harmonic voltages at each device will be conveniently cancelled. A key element in this design is to recognize, and design for, even harmonic open circuit terminations at the balanced balun port.

III. Load-Pull Transistor Measurements

To investigate the effects of the transmission line balun impedance conditions on a real device, a three-harmonic active load-pull measurement system was used to measure a Cree CGH40025F Gallium Nitride (GaN) high electron-mobility transistor (HEMT). The odd-mode impedance of an ideal balun, 25Ω, was presented to the fundamental and third harmonics, with an open circuit presented to the second harmonic. A model of the package parasitic components and an estimation of the drain-source capacitance (C_{DS}) were used to de-embed the waveforms to the current generator plane.

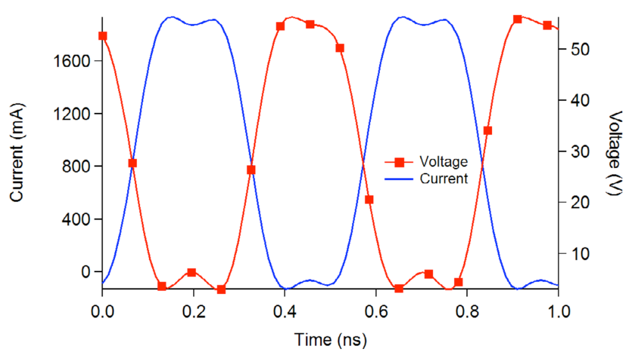

Fig. 3. Measured device plane RF voltage and current waveforms when presented with ideal balun impedances.

The waveforms shown in Fig. 3 were measured at 2GHz with the transistor operating in Class AB bias. As expected, due to the open circuit even-mode impedance, the current waveform contains no second harmonic component, but the third harmonic component has a small ‘squaring off’ effect, increasing the efficiency compared to a pure sinusoid.

The drain efficiency of this waveform is 65.80%, demonstrating the performance that would be achievable if the ideal balun impedances could be presented to the transistor at the current generator plane. In practice, C_{DS} and package parasitics, in addition to non-ideal balun structures will lower the drain efficiency.

IV. Design of Push-Pull Broadband Power Amplifier

The same Cree GaN HEMTs that were measured on the active harmonic load-pull system were used for the realized push-pull power amplifier. As has been previously outlined, filter-based matching networks limit the performance of the power amplifier for very broadband applications. For this design, a very simple matching topology was sufficient, based on the fact that the individual transistor loadline resistance was close to the odd-mode balun impedance of 25Ω.

The amplifier was designed with differential input ports, since a multistage design will very likely retain differential operation in at least the first driver stage. We also wished to allow for future investigations into the effects of input amplitude and phase imbalance. The current generator plane impedances presented by the differential output matching network are shown in Fig. 4. Note that the even harmonic impedances are reactive, due to the action of the balun. Although the spread of reactance over a decade bandwidth is not optimum for Class AB operation, the impedance environment is largely compatible with the ‘Class B-J’ design space described in [6].

A simple shunt-capacitor matching network was used at the inputs of the PA to increase the gain at higher frequencies.

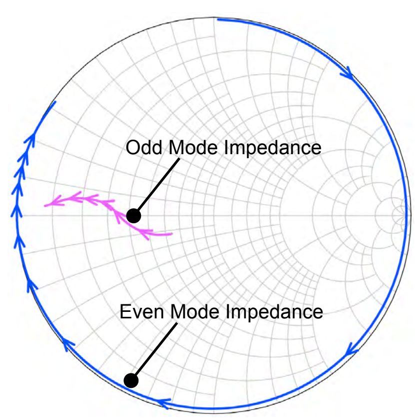

Fig. 4. Odd- and even-mode impedances presented to the transistor at the current generator plane from 400MHz to 3.25GHz.

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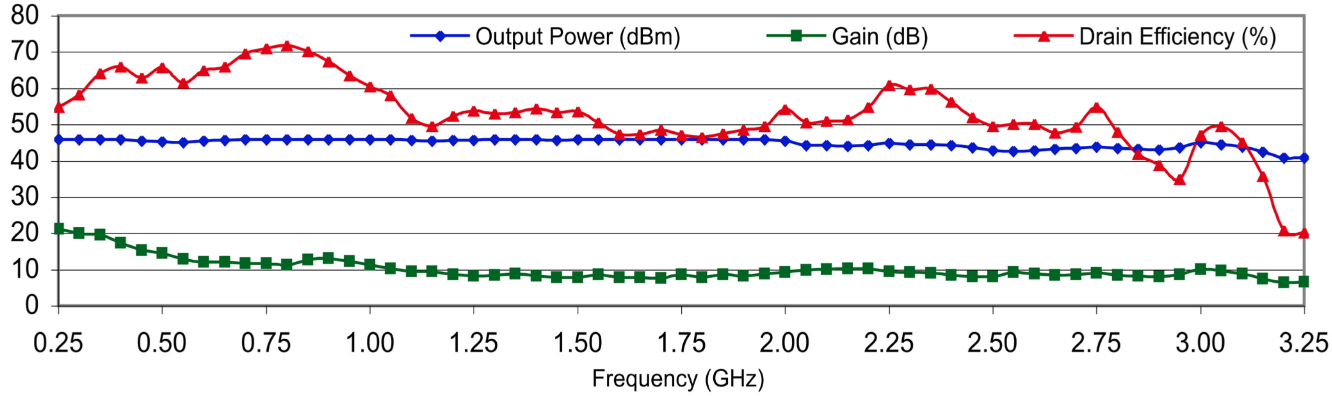

Fig. 5. Measured output power, transducer gain and drain efficiency of the realized push-pull output stage power amplifier.

It is expected that the output matching can be further improved by compensating for the package parasitic reactances at higher frequencies; this was not implemented in the present design since a chip-and-wire hybrid approach may be used in the future.

V. Realized Push-Pull Power Amplifier Performance

The design described in the previous section was manufactured on low-loss aluminium-backed circuit board. The slot required for the coaxial cable balun was milled directly into the aluminium, which served as the ground plane. The realized push-pull PA is shown in Fig. 6.

The output stage was driven by two signal sources with 180° phase offset. As can be seen in Fig. 5, the prototype push-pull PA exhibits 46dBm output power and greater than 45% drain efficiency between 700MHz and 2GHz. The PA has a minimum output power of 43dBm and high efficiency between 250MHz and 3.1GHz. In addition, a transducer gain and drain efficiency of over 11dB and 60% respectively were measured between 350MHz and 1GHz. Considering that packaged devices were used, the bandwidth and power levels presented are especially noteworthy.

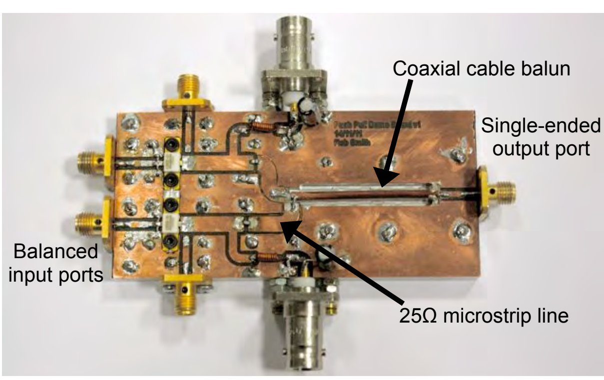

Fig. 6. Push-pull power amplifier with integrated coaxial cable transmission line balun at output.

VI. Conclusion

In order to realize a broadband, high-efficiency push-pull power amplifier at microwave frequencies, a coaxial cable transmission line balun was used to present a 2:1 impedance transformation ratio over a very wide bandwidth. When used with transistors with a comparable loadline resistance, the need for conventional filter-based matching is greatly reduced.

The bandwidth potential of the push-pull configuration has been demonstrated through the measurement of a prototype output stage PA. Output powers greater than 43dBm and high drain efficiencies were measured over a bandwidth greater than a decade. To the best of the authors' knowledge, the combination of bandwidth, output power and efficiency is the best reported to date.

Acknowledgement

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