Single-Ended Amplifier that Substantially Improves PAE and Ultra-Broadband Performance

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Abstract **A single-ended amplifier with a simple reactive matching is shown to provide stable operation with substantially improved amplifier power-added efficiency (PAE) (>30%) across an ultra-broadband frequency range (2-18 GHz). The amplifier employs a Double Pseudomorphic High Electron Mobility Transistor (DPHEMT) power device.**

Key words: **Microwave amplifiers, broadband devices**

I. INTRODUCTION

Ultra-broadband distributed or travelling wave [1], lossy matched [2], and feedback [3] amplifiers operating over the frequency range of 2-18 GHz have been investigated extensively by a number of researchers. The major deficiency of the latter amplifier concepts is that of poor output power and power-added efficiency performance across the 2-18 GHz frequency range. Typical power-added efficiencies for the distributed, lossy matched and feedback amplifiers fall in the range of 7 to 9 percent [4]-[5]. In the past, reactive matching circuit techniques have been employed in the design of single-ended amplifiers, however the instability problems restricts the amplifiers operating range to about an octave bandwidth [6]. This article demonstrates a novel 'stable reactively matched circuit concept' in which the design of a single-ended amplifier can achieve both high efficiency and (2-18 GHz) ultra-broadband operation. In addition, the amplifier exhibits excellent gain flatness, and input VSWR. The relative simplicity of the reactive match itself makes the realisation of the amplifier configuration conducive for MIC or MMIC technologies.

II. CIRCUIT CONCEPT

Conventional ultra-broadband amplifier designs are based on the travelling wave, feedback and lossy matched concepts. The circuit topologies of these amplifiers offer inherent stability across the ultra-wide bandwidth. These amplifiers also provide flat gain response, which is achieved by reducing the gain at low frequencies using resistive loading inherent in their circuit topology. The resistive loading at the output terminals of the active device leads to a non-optimum large-signal matching condition with the effect of degraded output power and efficiency. In order to optimise the output power and efficiency performance, it is usually necessary to match the output matching circuit into the large-signal impedance of the active device over the desired operational bandwidth.

In order to design single-ended amplifier for operation over an ultra-broadband (2-18 GHz), it is crucial to first derive accurate small- and large-signal models of the active device to be employed in the design. The simulation and optimisation of the single-ended amplifier circuit were then performed using Agilent Technologies ADS® simulation package. The active device used in the amplifier design was the state-of-the-art DPHEMT, i.e. LP6836 from Filtronic Solid-State. The small- and large-signal models of the DPHEMT used in the simulation were accurately derived, as described in reference [7]. The nonlinear Curtice-Ettenberg model [8] available in ADS® was used to derived large-

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signal model. The small-signal model was used for optimising the amplifier small-signal performance (i.e. gain level, gain flatness and input VSWR). The large-signal model was used to optimise the output power and power-added efficiency by matching the output circuit to the large-signal model.

The DPHEMT device LP6836 placed into a 50 ohm system without any impedance matching exhibits a gain roll-off and poor terminal VSWRs. At low frequency the device exhibits a substantial gain of 17 dB at 1 GHz, and at the high frequency end this gain is reduced to 3 dB at 19 GHz. The stability factor (k) of the device is less than unity. In order to achieve flat gain and circuit stability (i.e. the stability applies from theoretically DC to the maximum frequency operation of the device) over a bandwidth of 2-18 GHz, the broadband matching technique described in reference [9] was employed. This technique provides stable reactive matching in the single-ended amplifier with a flat gain response over the required frequency bandwidth.

The output network of the amplifier is designed to be matched into the large-signal impedance of the active device in order to optimise the output power and power-added efficiency. Incorporating the concept of close in resistive and reactive matching which is applied directly at the gate terminal of the device, as illustrated in Figure 1, provides broadband stability. This is achieved by the elements L_1, R and L_2 prior to any device matching. The consequence of this is a reduction in gain, albeit at the low frequency end. The active device parasitics, the elements L_1, R and L_2, and the input/output matching circuits determine the lower and upper frequency cut-off points of the gain response.

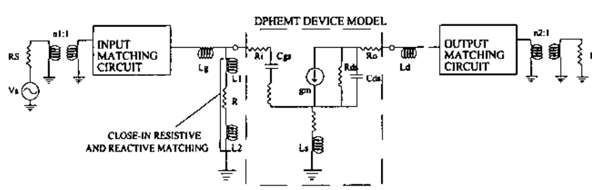

Figure 1. Electrical model of single-ended ultra-broadband high efficiency amplifier

Alumina substrate having a dielectric constant ε_r = 9.8 and a thickness h = 0.381mm was used as the microstrip medium. The computed stability factor (k) is greater than 1 over 0.001GHz to 50GHz, thus ensuring inherent circuit stability. Figure 2 shows the measured small-signal response over 2-18 GHz. The amplifier gain obtained is essentially flat at 8.5 dB and input/output return loss is better than 4 dB. The measured output power and power-added efficiency performances at 2 GHz, 12 GHz and 18 GHz are shown in Figure 3. This shows that the efficiency obtainable by this concept is greater than 30 percent and an output power in excess of 22 dBm. Further improvement in the terminal port impedances and output power can be achieved by configuring single-ended amplifiers into a balanced amplifier using broadband couplers.

Comparative analysis was performed on the design of a conventional travelling wave amplifier using the same active device and microstrip medium. The results of the optimised design and the measured power-added efficiency performance at 2 GHz and 18 GHz are shown in Figure 4. These results confirm good correlation between simulated results and measurements as well as the limited efficiency performance (6% @ 2 GHz and 8.5% @ 18 GHz) obtainable by using the conventional amplifier design concept.

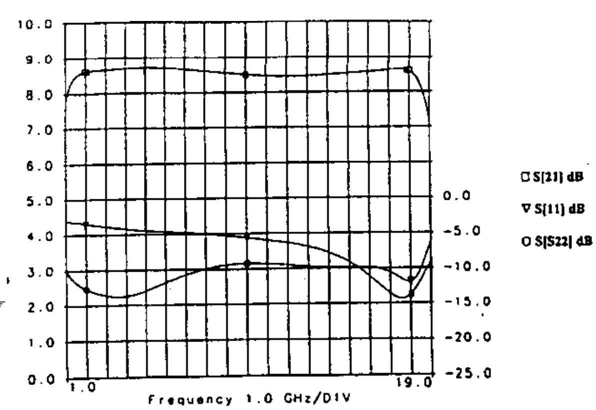

Figure 2. Small-signal circuit response of ultra-broadband single-ended amplifier

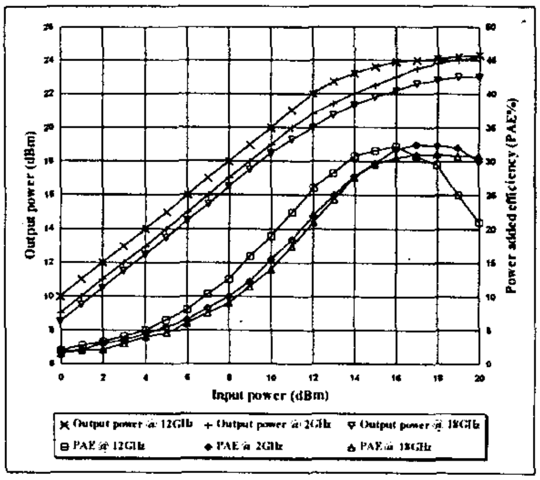

Figure 3. Output power and power-added efficiency performance of single-ended amplifier

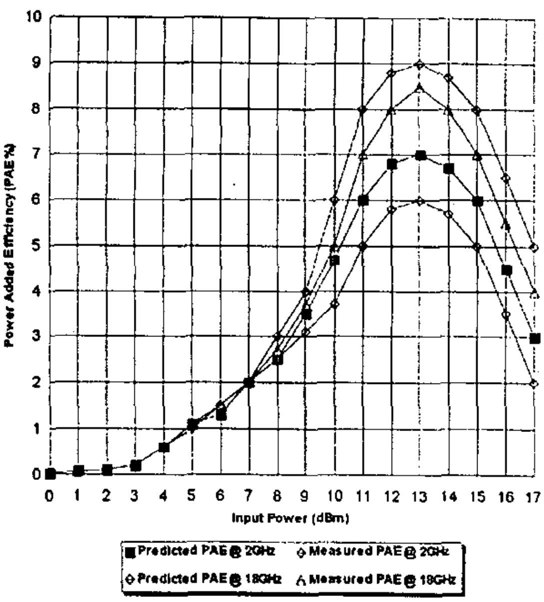

Figure 4. Predicted and measured power-added efficiency of a typical conventional travelling wave amplifier using same DPHEMT device as the single-ended amplifier

III. CONCLUSION

Single-ended amplifier design employing reactive matching concept is shown to be stable across an ultra-broadband frequency range (2-18 GHz). The amplifier exhibited an excellent power-added efficiency performance (>30%) over the ultra-broadband frequency range when compared to a conventional broadband amplifier design. In addition, unlike conventional broadband amplifier designs, the circuit concept offers a cost-effective solution as it uses a single active device and its circuit configuration is of a simple construction, which readily lends itself to MIC and MMIC technologies.

REFERENCES

[1] Y.Ayasli, L.D.Leonard, D.Reynolds, R.L.Mozzi and L.K.Hanes: '2-20 GHz GaAs Travelling-wave Power Amplifier', *IEEE Trans Microw. Theory Techn.*, 1984, MTT-32, pp.290-295

[2] K.B.Niclas: 'Reflective match, Lossy match, Feedback and Distributed Amplifiers: A comparison of multioctave performance characteristics', *IEEE MTT-S Symp. Digest*, 1984, pp.215-220

[3] K.B.Niclas et al: 'The Matched Feedback Amplifier: ultrawideband microwave amplification with GaAs MESFETs', *IEEE Trans Microw. Theory Techn.*, MTT-28, 1980, pp.285-294

[4] S.N.Prasad, J.B.Beyer, I.S.Chang: 'Power-Bandwidth Considerations in the Design of MESFET Distributed Amplifier', *IEEE Trans Microw. Theory Techn.*, MTT-36, 1988, pp.1117-1123

[5] Y.Ayasli, R.Mozzi, L.D.Reynolds, L.K.Hanes: 'Capacitively Coupled Travelling Wave Power Amplifier', *IEEE Trans Microw. Theory Techn.*, MTT-32, 1984, pp.1704-1709

[6] W.H.Ku, W.C.Peterson: 'Optimum Gain-bandwidth Limitations for Transistor Amplifiers as Reactively Constrained Active Two-port Networks', *IEEE Trans. Circuits and Systems*, CAS-22, 1975, pp.523-533

[7] A.S.Virdee, B.S.Virdee: 'High Efficiency Power Amplifier Design Using GaAs HFETs', *Microwave Journal*, October 1999, Vol 42, No 10, pp.108-124

[8] W.R.Curtice, M.Ettenberg: 'A Nonlinear GaAs FET Model for Use in the Design of Output Circuits for Power Amplifiers', *IEEE Trans Microw. Theory Techn.*, MTT-33, 1985, pp.1383-1394

[9] H.Carlin, J.Komiak: 'The Real Frequency Broadband Matching Approach', *IEEE Trans Microw. Theory Techn.*, MTT-27, 1979, pp.93-97