10W Ultra-Broadband Power Amplifier

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***Abstract* — We report the design and performance of an ultra-broadband power amplifier. It achieves 10 Watts output power with 21dB ± 1.5dB gain from 20 MHz to 3000 MHz. At lower frequencies from 20 to 1000 MHz the output power is 15 Watts with 22% efficiency. To achieve this performance, we employ a new design concept to control the device impedance and the power combiner impedance to be naturally 50 Ohms, such that no impedance matching is needed. Also, we developed a broadband microwave balun as a push-pull power combiner, which doubles as an impedance transformer. We believe the combination of output power, bandwidth and efficiency is the best reported to date.**

***Index Terms* — Power amplifiers, power combiners, broadband amplifiers, broadband balun, HIFET amplifiers.**

I. INTRODUCTION

Ultra-broadband power amplifier is a key component for instrumentation, software radio, broadband EW, etc. The challenge in achieving broadband performance with high output power and good efficiency stems from the fact that high power solid state devices have impedances much lower than 50 Ohms. It is very difficult to match very low impedance to 50 Ohms over broadband frequencies without substantial degradation in performance. Currently, the most popular technique to achieving ultra-broadband amplification is the traveling-wave amplifier approach [1-4]. Multiple devices are connected in a distributed configuration to simulate a 50-Ohm transmission line at all frequencies. The problem of this approach is that it uses many devices to achieve the same gain as a single device. Therefore, the efficiency, size, and cost are poor. To alleviate the above problem, we propose a new approach to achieving broadband, high-power, and good efficiency. Our approach is to design both the device impedance and the power combiner impedance to be 50 Ohms. Therefore, the amplifier is a nature 50-Ohm system such that no external impedance matching is needed over a very broad frequency band.

II. DESIGN CONCEPT

We use a two-tier design concept. We first tailor the device impedance to be 50 Ohms, which leads to a unit-cell MMIC power amplifier having 22dB gain, 4W output power with 50-Ohm impedance at the input and output ports. Then we develop an ultra broadband microwave balun to serve as power combiner and as an impedance transformer. With four 4W unit-cell amplifiers, we first parallel combine two unit-cell amplifiers to achieve 25-Ohm impedance. Then, we use this balun as a push-pull power combiner to combine the two 25-Ohm amplifiers. Because the push-pull configuration doubles the impedance at the output port, we achieve a 50-Ohm, 10W broadband amplifier with flat gain and good efficiency.

III. UNIT CELL MMIC AMPLIFIER

The unit-cell amplifier is a 2-stage MMIC PA that uses HIFET configuration [5-7]. The principle of this HIFET MMIC PA based on GaAs MESFET has been published in [8]. Briefly, the HIFET approach is to combine unit-cell active devices (GaAs FET in this case) both DC and RF in series, but thermal in parallel. Consequently, Both the HIFET DC bias voltage and RF output impedance are proportional to the number of unit cell in series. We can then design the proper device size to achieve 50-Ohm output impedance. In this case, no output impedance matching is needed, leading to very broadband performance with very small die size (2.27 x 2.3 mm). The packaged device is 7 x 7 mm.

We further improved the published MMIC MESFET PA performance (P1dB=34 dBm from 50 MHz to 2.500 MHz) using GaAs PHEMT. The improved result is shown in Figure 1. Figure 1 shows the output power P1dB and efficiency versus frequency. P1dB is very flat: 35 dBm ± 0.5 dBm from 20 MHz to 3500 MHz. The P1dB efficiency ranges from 30% at below 400 MHz to 22% at 3000 MHz.

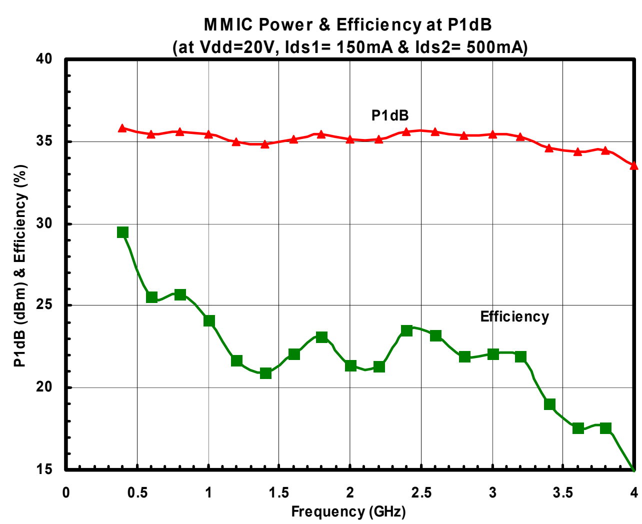

Fig. 1: Output power P1dB and efficiency as a function of frequency. P1dB is very flat, from 35dBm ± 0.5dBm from 20MHz to 3500MHz.

IV. BROADBAND BALUN AS POWER COMBINER

Broadband baluns have been used at audio frequencies for many years. Broadband microwave baluns have also been developed to cover bandwidth from few MHz to several GHz [9-10]. The availability of low loss ferrite materials at RF and microwave frequencies extends the same techiques used at few MHz to the Giga Hertz range. We report here a broadband microwave balun from 1MHz to 3000 MHz as shown below.

Figure 2 shows the input and output impedances of a 2-way balun, which serves as a power combiner/ impedance transformer. The input is a 50-Ohm coaxial line. The output is two microstrip lines. Both microstrip lines share the common MIC ground plane. Each has 25-Ohm impedance, but 180 degree out of phase. Ferrite cores are used to isolate the 180 degree output ground terminal from the input ground terminal.

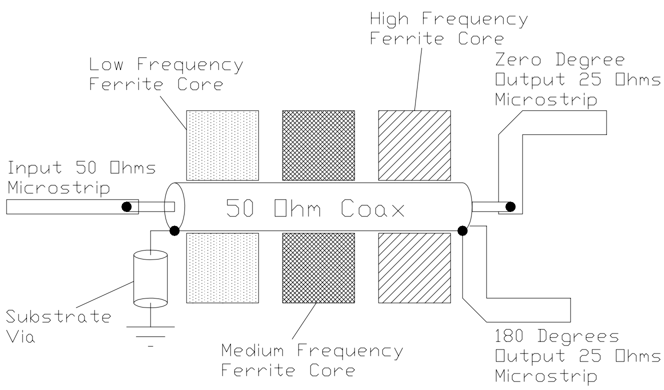

Fig. 2. 2-way Balun, which serves as a power combiner / impedance transformer.

The impedance at the input port is 50 Ohms. At the two output ports, the impedance is 25 Ohms each with 180 degree phase difference. For a 4-way combiner, the impedance at the output port will be 12.5 Ohms. This type of power combiner is very desirable because the combined output power is not just proportional to the n-way of 50-Ohm amplifiers being combined. It is actually proportional to n^2 of 50-Ohm amplifier being combined (Minus the combiner loss), as shown below:

Total Output power = $n^2 \times P_0$ – combiner loss

Where "n" is the number of split, and P_0 is the output power of the 50-Ohm unit cell amplifier.

Because the impedance at the output port of a 2-way balun is 25 Ohms, we can use 25 Ohms as our reference impedance. Therefore, we can either double the device size to achieving twice the device output power (At 25-Ohm impedance), or first combine two 50-Ohm PA to achieve 25 Ohm.

Because ferrite has only limited bandwidth, we use three commercial ferrites beads in series to achieve broad band. These ferrite beads act like chokes so that the currents of inner and outer conductors of the coaxial line are equal and opposite in direction. The bead model numbers are 2673003201, 2643003201 and 2661006701 from FairRite. Model 2673003201 covers 1MHz to 10MHz, 2643003201 covers 10 MHz to 200 MHz and model 2661006701 covers high frequencies above 200 MHz. Note that the high frequency Ferrite core is placed near the balanced ports and the lowest frequency Ferrite core near the unbalanced port.

Figure 3a is the photograph of a prototype 2-way balun connected back-to-back for easy characterization. Figure 3b shows the performance of this back-to-back 2-way balun. The balun covers 1MHz to 2500 MHz. The loss of a single balun is 0.25 dB at low frequency, and 1.3 dB at 2500 MHz.

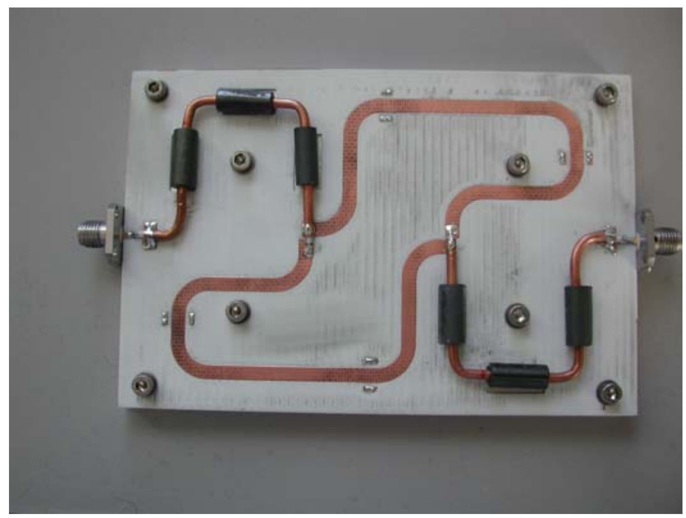

Fig. 3a. Photograph of a prototype 2-way balun.

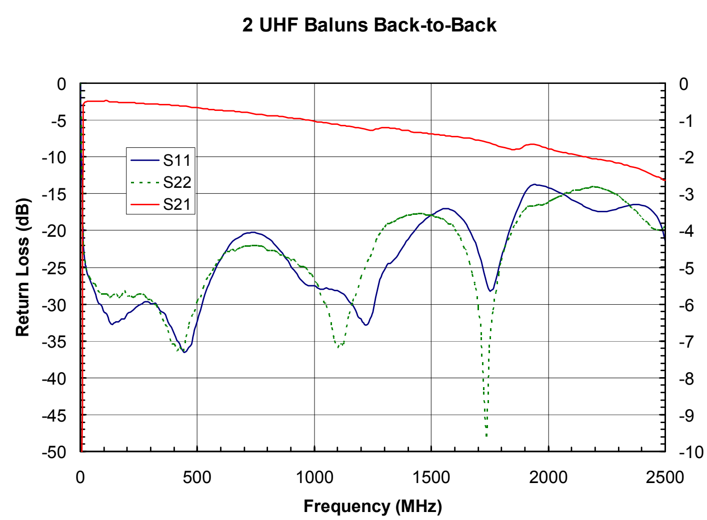

Fig. 3b. Performance of this back-to-back 2-way balun.

V. Ultra Broadband PA Performance

Figure 4 is a photograph of the ultra-broadband amplifier. It consists of four 50-Ohm unit cell MMIC amplifiers. Two unit cell amplifiers are directly combined to reach 25-Ohm impedance. Then, a 2-way balun is used to power combine these two 25-Ohm amplifiers to achieve 50-Ohm output impedance. The amplifier is packaged in Aluminum housing with SMA connectors for RF input and output, and DC pins for DC bias. The dimension of the housing is 6” (L) x 4” (W) x 0.66” (H). Figure 5 shows the small signal gain and return loss versus frequency of this amplifier. The small signal gain is 21dB ± 1dB from 20 MHz to 3000 MHz. The amplifier is usable up to 4000 MHz with reduced gain and power.

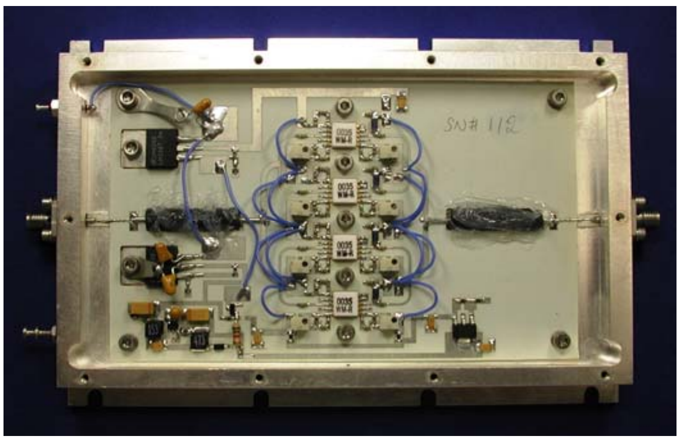

Fig. 4. Photograph of ultra broadband amplifier

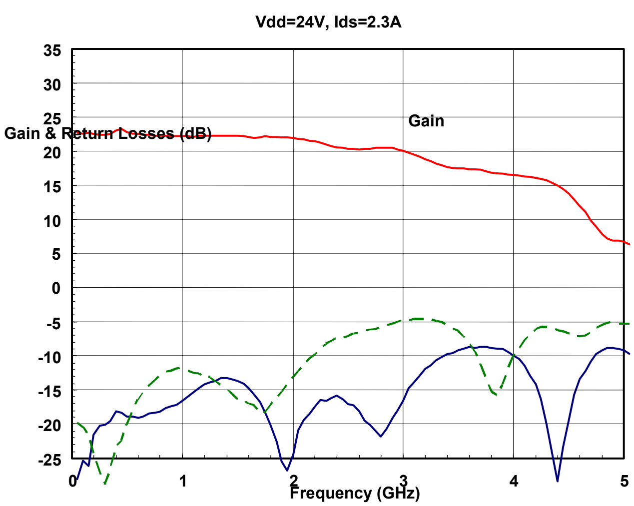

Fig. 5. Small signal gain and return loss versus frequency. The gain is 21 dB ± 1 dB from 20 MHz to 300 0MHz.

Figure 6 shows the output power P1dB, P3dB and small-signal gain versus frequency. P1dB is 15 watts from 20 MHz to 1000 MHz, and gradually decreased to 10W at 3000 MHz. The PA is usable up to 4000 MHz. Figure 7 shows the efficiency versus frequency. The P3dB efficiency is 25% below 100 MHz, and drops to 14% at 3000MHz, partially due to the loss of power combiner. Figure 8 shows IP3 and IP5 versus frequency. IP3 is 58 dBm up to 500 MHz, and 48 dBm at 3000 MHz. From Figure 6, P1dB is 42dBm up to 500 MHz. Yet, IP3 is 58 dBm up to 500 MHz. Therefore, IP3 is 16 dB above P1dB. This shows the excellent linearity of this amplifier.

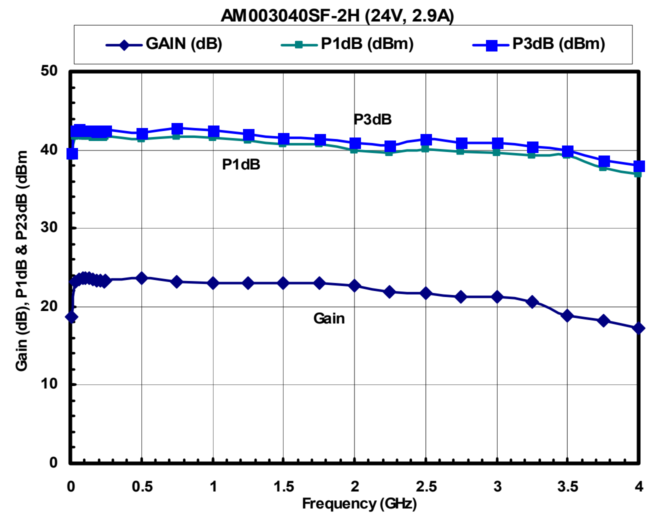

Fig. 6. Output power P1dB and P3dB versus frequency

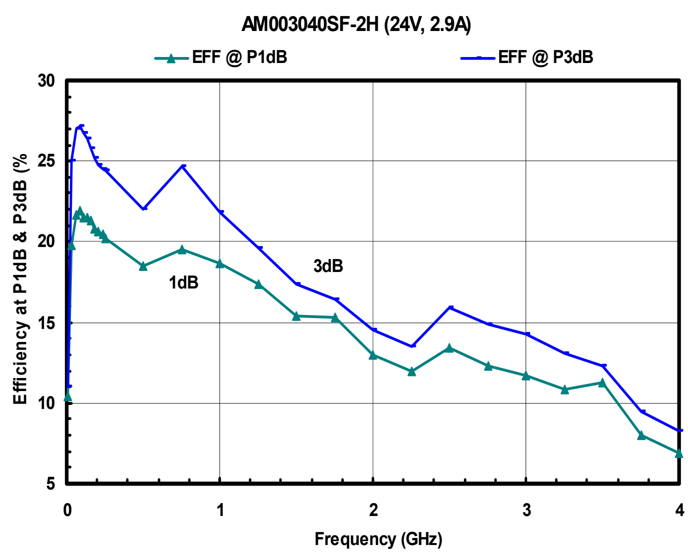

Fig. 7. Efficiency at P1dB and P3dB versus frequency

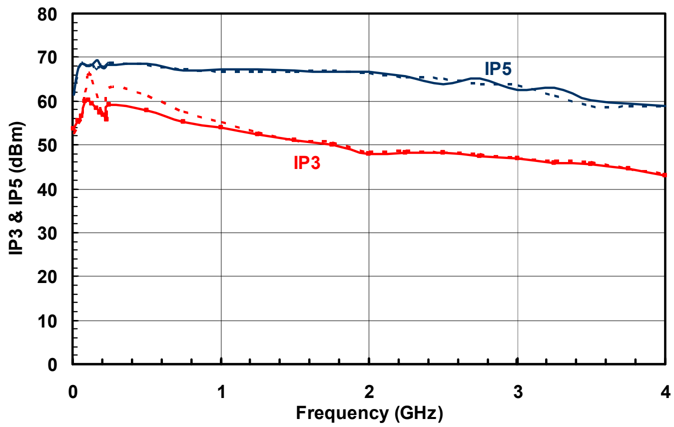

Fig. 8. IP3 and IP5 versus frequency.

VI. CONCLUSION

We have presented a new concept to achieving ultra broadband, high-power, and high-efficiency power amplifier by the proper control of both device impedance and power combiner impedances to be naturally 50 Ohms. We have also developed a broadband microwave balun which serves as a power combiner / impedance transformer.

We have reduced this concept to practice. The amplifier achieves 10 watts output power with 21dB gain and good efficiency from 20 MHz to 3000 MHz in a single band. We believe that our design approach, as well as the combined performance of bandwidth, output power, efficiency, and linearity is the best reported to date.

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