A Power Amplifier Based on an Extended Resonance Technique

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Abstract—**A new power amplifier based on an extended resonance technique is presented. This technique produces high power through multiplying the power handling capability of a single device by the number of devices employed while maintaining the gain of a single-device amplifier. An X-band power combining amplifier employing four 100 mW MESFET's was designed and constructed. The small signal gain was measured at 11.5 dB, and a maximum of 480 mW was obtained at 9.57 GHz with a power-added efficiency of 30.8%.**

I. INTRODUCTION

A POWER-combining oscillator based on an extended resonance method was introduced in [1]. In this letter, a power-combining amplifier based on an extended resonance technique is introduced. The usual technique of designing high power amplifiers employs Wilkinson-type power combiners or four-port hybrids to power combine many amplifiers. The power-combining amplifier described here, however, essentially places many active devices in shunt with each other. This technique yields very compact circuits, does not require matching circuits for individual devices, and provides for simple biasing. The extended resonance technique employed herein is superficially similar to a distributed amplifier design [2] but is actually quite different in its performance. For instance, the amplitude of the voltage at each device port is the same, and the gain of the multiple device circuit is the same as that of a single-device amplifier regardless of the number of devices in the structure. Furthermore, this design does not use resistors to terminate the input and output lines.

II. THEORY

For simplicity we consider an extended resonance circuit incorporating N two terminal devices as shown in Fig. 1. Throughout this discussion it is assumed that all the admittances are normalized to the characteristic admittance of the lines, and that all the lines have the same characteristic admittance. The admittance of the first and the last device is $Y = G + jB$ while the admittance of each interior device is $Y = G + 2jB$. The length of transmission line L_1 can be chosen such that the admittance of the first device is transformed to its conjugate, namely $G - jB$. Therefore, the admittance seen by looking at the terminals of the second device is $y_2 = 2G+jB$. As can be seen in this process half of the susceptance of the second device is canceled. The length of the transmission line L_2 can now be chosen to convert $2G + jB$ to $2G - jB$, which cancels half the susceptance of the third device. This process is done $N - 1$ times. The admittance seen looking at the terminals of device $(N-1)$ will be $y_{N-1} = (N - 1)G + jB$. The length of the transmission line L_{N-1} can then be chosen such that $(N - 1)G + jB$ is transformed to $(N-1)G-jB$ which resonates the admittance of the last device. The admittance seen at the terminals of the Nth device is NG, which is matched to the source conductance with a quarter wave transformer. Resonating all the devices with one another essentially places them in shunt (the analytical proof is omitted for brevity). Analysis of this structure shows that the voltage at each device port differs in phase, but not in magnitude (indeed, this is a very important fact that makes such circuits very useful in the design of power combining amplifiers and oscillators). For an arbitrary device n, the reflection coefficient at the terminal of the nth device (see Fig. 1) is

$$\Gamma_n = R_n e^{j\alpha_n} = \frac{1 - y_n}{1 + y_n}. \quad (1)$$

The voltage phase shift between devices n and $n + 1$ can be represented by

$$\phi = -m\pi - \alpha_n + 2\tan^{-1}\left[\frac{R_n \sin\alpha_n}{1 + R_n\cos\alpha_n}\right] \quad (2)$$

where $m = 0$ for $0 < \alpha_n < \pi$, and $m = 1$ for $-\pi < \alpha_n < 0$.

Let us now consider a simplified N device extended resonance power amplifier incorporating MESFET's, shown in Fig. 2. The gate and drain extended resonance circuits can be designed separately after calculating the simultaneous conjugate match admittances. It is assumed that the admittance seen looking into the gate of each device is $Y_g = G_g + jB_g$ while the admittance seen looking into the drain of each device is $Y_d = G_d+jB_d$. The gate circuit design follows the previously described extended resonance procedure starting at the gate of the first device and ending at the gate of the Nth device. As shown in Fig. 2, the interior devices' extra susceptance jB_g is provided by shunt capacitors (or inductors). One can use stubs to provide the necessary inductance or capacitance values. The drain circuit design is similar, starting at the drain of the Nth device and ending at the drain of the first device. There is, however, an additional requirement that the voltage phase difference between successive drains be equal to the voltage phase shift between successive gates. Using (2), one can solve for the admittance seen looking into the output circuit at the terminal of the nth device, $y_{on} = g_{on} + jb_{on}$ (where y_n in

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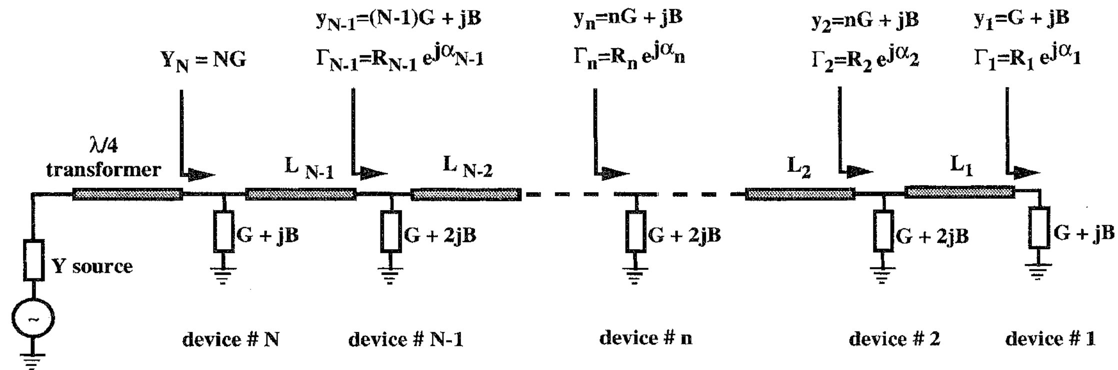

Fig. 1. Extended resonance concept using two terminal devices. All the admittances are normalized to the line admittance.

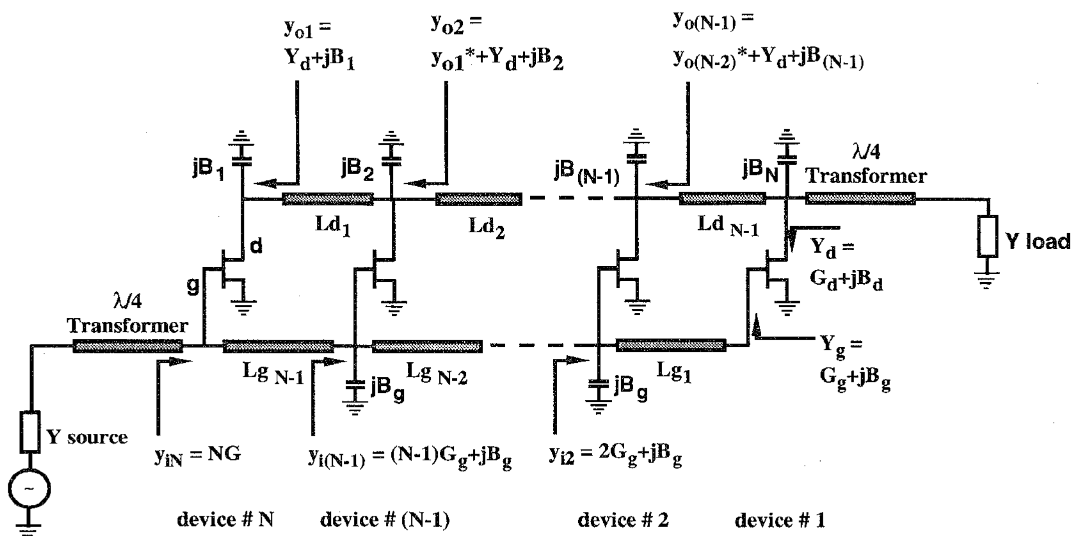

Fig. 2. A simplified extended resonance power amplifier using MESFET's.

(1) is replaced by y_{on}), to provide the required phasing. For a given phase shift between device n and device $n-1$, there is an infinite number of y_{on} that satisfy (2). This may give the designer freedom to assign the values $g_{\text{on}} = nG_d$. The required values for jb_{on} can then be determined from (2). A shunt susceptance, jB_n, is added to each terminal to obtain the required jb_{on}.

III. Experiment

To demonstrate the extended resonance power-combining amplifier, a four-device power amplifier was designed and fabricated. A single-device amplifier was also fabricated to facilitate the determination of the power combining efficiency of the four device amplifier. The active devices used were Alpha power GaAs MESFET chips AF035P1-00 having a gate length of 0.25 μm and a total gate periphery of 400 μm. Devices were biased at 5 V with a drain current of 70 mA. The amplifiers were fabricated on a 31-mil-thick Duroid™ substrate with $\varepsilon_r = 2.3$. Fig. 3 shows the measured small signal gain and return loss for the four-MESFET power amplifier. The maximum gain is 11.3 dB at 9.5 GHz and closely approximates the predicted gain. The output power and gain at 9.58 GHz are 400 mW and 8 dB, respectively, and

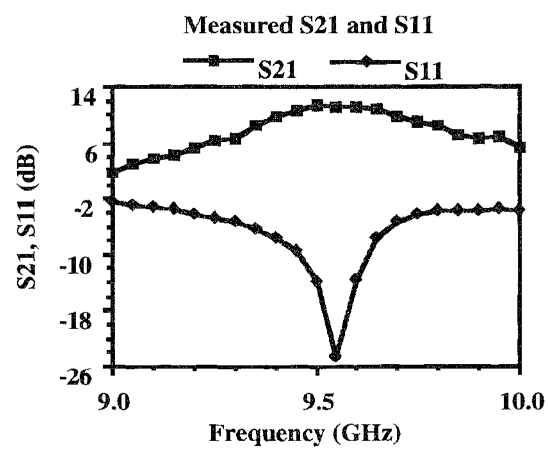

Fig. 3. Measured small signal gain and return loss for the four-MESFET power amplifier.

the power added efficiency is 27%. This corresponds to the 3 dB compression point. At 5.1 dB compression, the output power and power added efficiency were 487 mW and 30.8%, respectively. The single-device amplifier exhibited a maximum small signal gain of 11.5 dB at 9.6 GHz and it provided 111 mW output power with a power added efficiency of 33.7% at the 3 dB compression point. Both the four-device power amplifier and the single-device amplifier exhibited a 3-dB bandwidth of 5%.

This experiment confirms our claim that the extended resonance power-combining technique multiplies the power handling capability of a single device by the number of devices employed while maintaining the gain of a single device.

IV. Conclusion

A technique to design high power amplifiers based on an extended resonance method was described. This technique can yield compact power-combining structures. Results achieved from a four-device extended resonance power-combining amplifier were presented. These results closely matched those from a single-device amplifier. Further research is being conducted using techniques that can increase the existing bandwidth. Anticipated goals for the extended resonance power combining amplifier include its implementation in monolithic form at millimeter wave frequencies.

Acknowledgment

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References

[1] A. Mortazawi and B. C. De Loach, Jr., "Multiple element oscillators utilizing a new power combining technique," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 2397–2402, Dec. 1992.
[2] G. D. Vendelin, A. M. Pavio, and U. L. Rohde, *Microwave Circuit Design Using Linear and Nonlinear Techniques.* New York: Wiley Interscience, 1990.