A QUASI-OPTICAL LINEARIZER

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Abstract— **A quasi-optical linearizer array with bias controllable AM-AM and AM-PM predistortion characteristics is presented. The 4×4 array of Schottky diodes demonstrates 2.5 dB of gain expansion and 25° of phase compensation at L band.**

I. INTRODUCTION

POWER amplifiers are typically driven into saturation to meet system requirements for power and efficiency. However, since both the gain and the phase shift through the amplifier are functions of the input drive level, the high power and efficiency performance comes at the expense of degraded amplitude and phase linearity, resulting in AM-AM and AM-PM distortion in the transmitted signal. For modulation schemes in which information is encoded in both the amplitude and phase of the carrier wave, it is clear that both amplitude and phase linearity are needed.

Shown in Fig. 1 are typical transfer characteristics for a MESFET-based power amplifier. The point of maximum power-added efficiency occurs when the gain is 4-dB compressed. This is accompanied by a phase shift that is advanced 15° with respect to its small-signal value.

To counteract these distortion effects, a predistortion linearizer [1] can be inserted before the amplifier to create a signal distortion that is opposite to that of the amplifier. In other words, the linearizer should exhibit gain expansion and phase delay as the input power increases. This would result in an amplifier with greater dynamic range.

This paper demonstrates the first free-space linearizer array that can be cascaded into a quasi-optical transmitter front end. Research in quasi-optical amplifiers has recently demonstrated improvements in power [2]–[4], efficiency [5], and operating frequency [6], [7]. As communication applications for these amplifiers emerge, maintaining linearity will also become a critical issue.

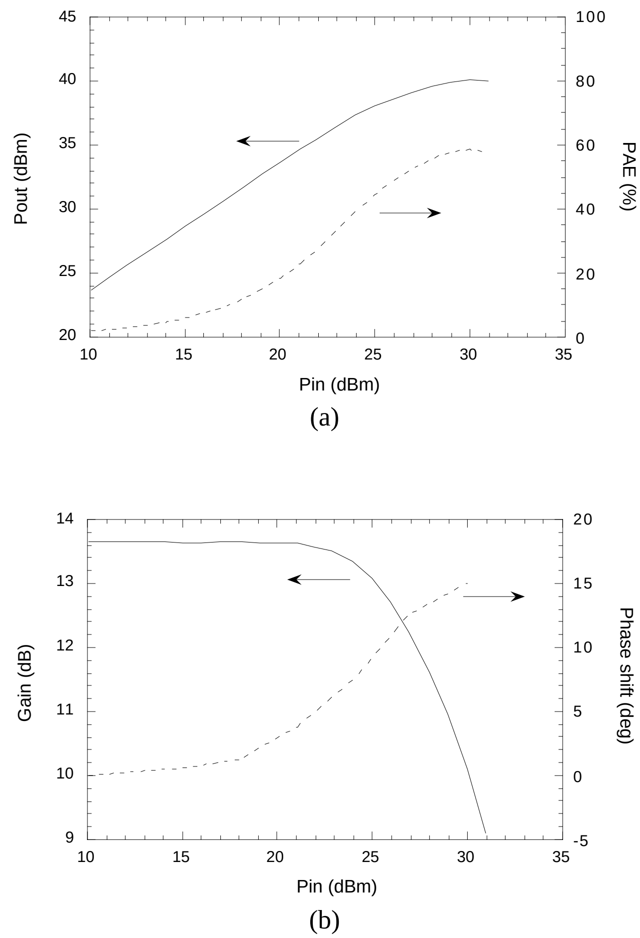

Fig. 1. Measured characteristics of a 36-W, MESFET-based (Fujitsu FLM3742) power amplifier: (a) output power and power-added efficiency as a function of input power, and (b) amplitude and phase transfer characteristics.

II. DESIGN

The configuration for the 4×4 quasi-optical linearizer is shown in Fig. 2. The unit-cell is 4 cm $\times$4 cm (λ_o/8 square at 1 GHz) with 2-mm-wide bias lines and radiating leads. The substrate is 0.254-mm-thick *Duroid* with $\epsilon_r = 2.2$. The grid is loaded with Metelics MSS-40,045-E28 medium-barrier Schottky diodes. A series chip resistor is connected at the edge of alternating rows. The equivalent circuit model for a single unit cell is shown in Fig. 3. The lead inductance and capacitance for the grid are determined from a full-wave model for the grid [8].

The principle of operation is based on the diode linearizer in [9], and is summarized here for completeness. The diode current is given by

$$I_d = I_s \left(1 - \mathrm{e}^{-qV_d/kT}\right)$$

where V_d is the diode voltage and I_s is diode saturation current.

As the RF input power increases, the parallel diode produces a rectified current I_r that induces an additional voltage drop across the bias resistor R_b:

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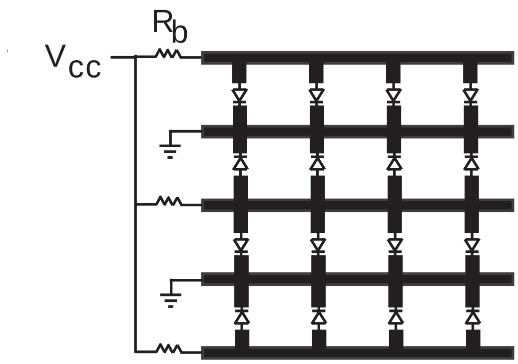

Fig. 2. A Schottky-diode linearizer array. Bias resistors are connected at the ends of alternating rows.

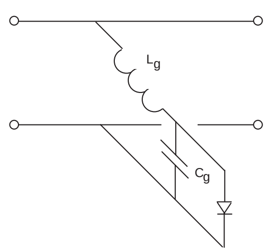

Fig. 3. Equivalent circuit of a unit cell with lead inducatance and gap capacitance.

$$V_d = V_{cc} - R_b(I_d + I_r)$$

The reduction in the diode voltage under large-signal conditions causes an increase in the diode dynamic resistance given by

$$R_d(V_d) = \frac{1}{\partial I_d / \partial V_d} = \frac{kT}{qI_s} \mathrm{e}^{-qV_d/kT}$$

Using the equivalent circuit model in Fig. 3, together with the manufacturer's packaged parasitics for the diode, an expression for S_{21} was derived. Fig. 4 shows that as the diode resistance increases, the result is gain expansion and phase delay. These are the characteristics required to linearize an amplifier such as the one in Fig. 1.

III. Experimental Results

The linearizer was measured using a power sweep on an HP 8753B network analyzer. Each port of the network analyzer was connected to a wideband horn antenna. The diode grid was placed 10 cm away from the source horn and 45 cm away from the receive horn. To drive the diodes into saturation, a 4-W power amplifier was used at Port 1. The incident power on the grid ranges from 0.25 W to 2.5 W. A free-space through calibration with the grid in place was performed.

Fig. 5 shows the gain and phase compensation characteristics for one combination of bias voltage and resistance. For

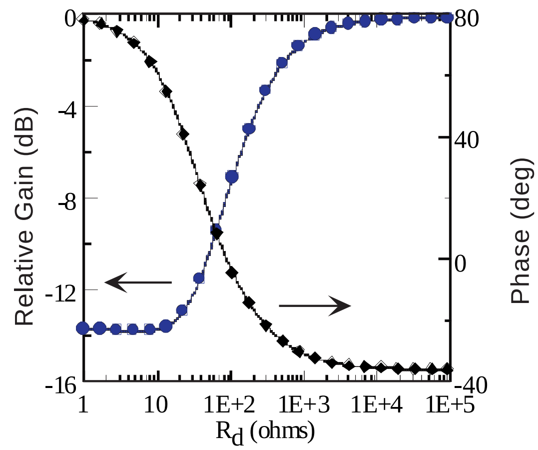

Fig. 4. Simulated gain and phase compensation at 1 GHz. The increase in R_d is an indirect measure of the increase in RF power.

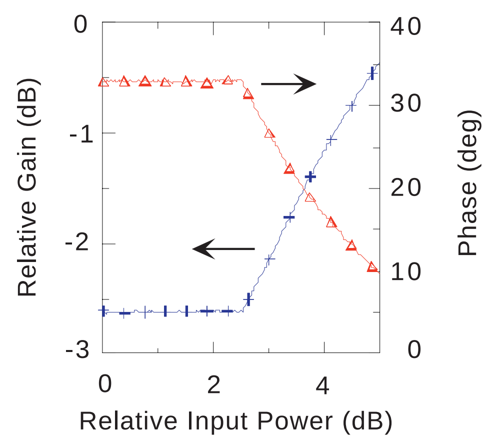

Fig. 5. Measured gain and phase compensation for $R_b = 470\,\Omega$ and $V_{cc} = 11\,\text{V}$.

this case, the gain expansion was 2.5 dB and the phase compensation was $25°$ at 1 GHz.

At higher frequencies, the linearizer demonstrated as much as 12 dB of gain expansion and $60°$ of phase shift. Since amplifiers typically achieve maximum efficiency at 3-4 dB gain compression, such large values of gain correction are not required.

Individual elements in a free-space-fed amplifier may saturate nonuniformly, and therefore the required amount of gain and phase predistortion will also be nonuniform. The linearizer array architecture of Fig. 2 can account for this by using different bias resistors on peripheral vs. central rows. Fig. 6 shows that adjusting the diode voltage allows different amounts of phase delay. The amount of gain expansion can similarly be adjusted. Of course, there are other quasi-optical amplifier architectures that facilitate uniform field excitation across the array [10], [11].

The nonlinearity in single-tone amplifiers is characterized

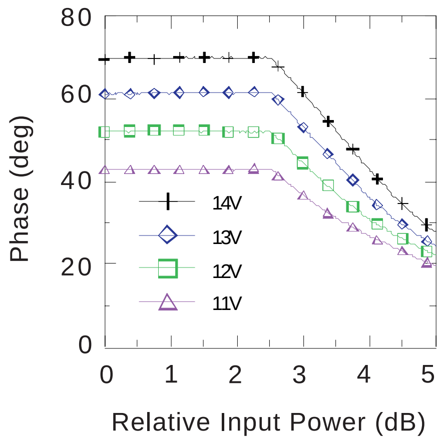

Fig. 6. Phase compensation as a function of diode bias.

by the AM-AM and AM-PM transfer curves, as in Fig. 1. For multitone applications, the nonlinearity manifests itself as intermodulation distortion and adjacent channel interference. Since the predistortion linearizer is itself nonlinear, it creates its own intermodulation products that add out of phase with those of the amplifier.

A two-tone linearity test was conducted using input frequencies of 2.10 GHz and 2.11 GHz. Although the spectrum analyzer could not measure the phase of the resulting third-order intermodulation products, their role would be to cancel the intermodulation products of the succeeding power amplifier. Future work with collaborating investigators will focus on the linearization of quasi-optical amplifier to achieve simultaneous high efficiency, linearity, and dynamic range.

IV. Conclusion

A free-space linearizer that can be inserted into a quasi-optical transmitter has been presented. It demonstrates 2.5 dB of gain expansion and $25°$ of phase compensation at L-band.

Acknowledgments

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