necessary to use a sensible value for λ to obtain a solution at the correct temperature change.

III. Conclusion

Self-heating effects in FET models must be complete. Otherwise, as pointed out by Maas, the simulation can become ill conditioned. It is important to model all aspects of temperature variation. Then, if, and only if, the parameters and model have been chosen correctly, any ill conditioning would correctly indicate a thermal runaway or instability in the real circuit. In general, if temperature dependence of mobility is included, then there will always be a solution.

References

[1] A. E. Parker and J. G. Rathmell, "Measurement and characterization of HEMT dynamics," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 2105–2111, Nov. 2001.

Author's Reply

Stephen Maas

In his comments, Prof. Parker makes the point that a properly designed model should not predict thermal instability or have multiple solutions in a device that is thermally stable, and, if it does, the model is not doing its job. I certainly cannot disagree with that point.

The issue addressed in the letter[1] goes a bit beyond this, however. Since self-heating models are inherently nonlinear, and many model designers seem unable to avoid equating complexity with accuracy, it is almost inevitable that multiple solutions can occur, under some conditions. A harmonic-balance analysis searches over a wide range of its independent variables (usually voltage components) to find a solution, so multiple solutions, even at unrealistic temperatures, are likely to be discovered. Models are frequently formulated to work in the expected range of temperatures, and often are not robust outside of that range. Another concern is the existence of indistinct solutions, which can lead to convergence failure in harmonic-balance analysis. These conditions can be maddeningly difficult to avoid and puzzling to the user when they occur.

Indeed, the above example can be modified to make it ill conditioned. If $R_{\rm th}$ is approximately 5.5, the $\lambda = 0.007$ case shows multiple solutions; even the $\lambda = 0.02$ case may be sufficiently indistinct to slow convergence at certain values of $R_{\rm th}$. Of course, as suggested in the comment, increasing λ removes the ill conditioning, but what if the user decides that $\lambda = 0.007$ describes his device most accurately within the expected range of operation? Or, what if he decides that a quadratic model, or other simple model, is not adequate, and therefore increases the complexity? I think it is important to know the consequences.

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[1]S. A. Maas, *IEEE Microwave Wireless Compon. Lett.*, vol. 12, pp. 88–89, Mar. 2002.

Comments on "Improvement of Broadband Feedforward Amplifier Using Photonic Bandgap"

Thomas J. Ellis

***Abstract*—A number of technical facts were either claimed or implied in the above letter, which appeared in the November 2001 issue of IEEE Microwave and Wireless Components Letters. Without clarification or supporting data, the claims presented could mislead the reader into drawing inaccurate conclusions regarding the performance increase of feed forward amplifiers due to the so-called photonic bandgap structure.**

***Index Terms*—Feedforward amplifier, photonic band gap.**

I. Introduction

In the above letter,[1] some general claims are made that a photonic band gap (PBG) enhanced feed-forward amplifier shows a 4% increase in power added efficiency (PAE), a 15 dB reduction in intermodulation distortion, and a doubling of the bandwidth, as compared to a "conventional feed-forward" amplifier. The data and explanations presented in the paper do not appear to support the claims, and the data that was presented does not appear to be consistent with the explanations in the accompanying text.

It is important to note that the popular PBG structure used for the claimed improvement is essentially a large, distributed, stepped impedance filter whose response can be completely predicted using cascaded transmission line analysis. This type of structure was initially investigated at The University of Michigan in 1996 and 1997 [1], and was not pursued for publication.

The headings of this letter will follow those of the original paper, with questions and inconsistencies being contained in the corresponding sections.

II. Main Amplifier Design and Measurement

It was reported that the "main amplifier" was based on an "NE650 FET," which is assumed to be the NE6 500 496 GaAs FET. The authors report a "theoretical" gain of 11 dB, which is consistent with the manufacturers data sheet, but an "actually manufactured" gain of 8 dB with a class A bias point of 8 V, 500 mA. Having the fabricated amplifier to perform significantly worse than the manufacturers data sheet would imply a nonoptimal design. This could seriously skew any conclusions drawn from the "improvements" gained by using the distributed filter structure (i.e., PBG), which will be explained in more detail later.

The authors report that the amplifier was used at an output power level of +28 to +30 dBm. With the bias point listed (which may be more class AB bias), the resulting efficiency should be 25% and not the 8%–12% listed.

The authors claim that adding the PBG provides a 3-dB improvement in intermodulation distortion (IMD). The linearity of a power amplifier is sensitive to the load impedance presented to the output of the transistor. If the PBG effect truly caused the decrease in distortion, it would have presented a purely 50-Ω load to the output of the amplifier

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[1]J. Yoon and C. Seo, *IEEE Microwave Wireless Compon. Lett.*, vol. 11, pp. 450–452, Nov. 2001.

for in-band signals. Without providing the impedance of the "PBG" section to show this, it may be concluded instead that the filter merely alters the output match, as seen by the transistor, thereby changing the overall linearity, or more properly terminating the harmonic content of the output.

It is shown in Fig. 2 of Yoon and Seo that the combination of different linearization techniques yields a 20-dB reduction in IMD products, which would be quite significant. However, the authors cite references and claim only a 12-dB decrease. Also, the difference in distortion levels with and without the so-called PBG structure appears quite marginal.

The authors also state that the PAE of the amplifier increases due to lower distortion, which is true when the output power of an amplifier can be increased for a fixed level of distortion, but the PAE of a feedforward amplifier depends on a number of additional factors not related to the main amplifier.

III. Feedforward Design and Measurement

The authors claim that with predistortion, harmonic tuning, and PBG, it was possible to operate the device at a point 2 dB from the reported compression point of +36 dBm while maintaining a distortion level of −30 dBc. In addition to being inconsistent with experience, that level does not appear to agree with the levels displayed in the graph of Fig. 2.

In Section II, the amplifier was reported to have a bias point of +36 dBm (dc power). If the total feed-forward dc system power were now +35.5 dBm, then the "driver amp" would have a net *negative* dc power of 0.5 dBm.

With respect to Fig. 3, the 4% increase in PAE represents a relative improvement of 50% in PAE with the use of the different techniques. Such a large relative improvement seems to reinforce the likelihood of a nonoptimal initial amplifier design.

The conclusions of the bandwidth of the amplifier seem to be drawn from the 3-dB bandwidth as presented in Fig. 4. To claim such broad bandwidths for a power amplifier, the gain, linearity, and efficiency would need to be presented, as well. It also appears that this may be the response of the HPA only, and not of the "feed forward" system. Assuming the graph reports the response of the HPA only, there seems to be little difference between the reference design and the "improved" designs, except that the reference design seems to have a better response around the center frequency. There is also, again, very little difference shown due to the PBG filter structure.

The authors report the measured results of the feed forward system, using a 2-tone, 1-MHz separated signal and claim a −70 dBc performance. It is not clear from the graph what the total output power is. However, the graph presented does not appear to be measured data at all, but the results of a two-tone harmonic balance simulation using Agilent's Advanced Design System software.

IV. Conclusion

The title of the listed paper implies that the feedforward amplifier system benefits from the distributed filter structure referred to as photonic bandgap. However, the information provided shows only that the original levels of IMD are 15 dBc lower on an amplifier using the listed techniques (not just PBG, as the title of the paper would imply), and that seems to be for a very specific operating condition. There is also a questionably small difference in the IMD levels with and without the filter structure. While the absolute level of IMD from a feed forward system is directly related to the IMD of the main amplifier, the relative improvement provided by the feedforward system is not.

The paper also concludes that the bandwidth of the feedforward amplifier is now double that of a "conventional" design. The data provided only shows a possible increase in the 3-dB bandwidth of the main amplifier, and it does not show the distortion levels for those frequencies. To show that a feedforward system was improved, the measured distortion products would need to be measured across the reported frequencies with all other components of the system held constant.

It is important to note that under a controlled laboratory environment, it is possible to prototype a low power feed forward system and achieve arbitrarily small levels of distortion. To do a fair comparison of the effects of the PBG or other linearization techniques on the performance of a feed forward amplifier, extreme care would need to be taken to ensure that no other component of the feed forward system was changed except those listed.

A feedforward system works by isolating the distortion products from a signal and injecting them *forward* in the signal path in a manner to cancel out the original distortion. The performance of the system is related to how well the distortion can be isolated and how well the amplitude and phase of the distortion can be controlled so as to recombine out of phase and cancel. There does not appear to have been any data shown to conclude that a feedforward amplifier performance (linearity, efficiency, bandwidth, etc.) was improved in any way by the so-called PBG structure or other techniques reported.

References

[1] J. D. Shumpert, T. J. Ellis, G. Rebeiz, and L. P. B. Katehi, "Microwave and millimeter-wave propagation in photonic band-gap structures," Univ. Michigan, Internal Radiation Lab. Rep. RL-953, Oct. 1997.