LINEAR, HIGH EFFICIENCY POWER AMPLIFIER SOLUTION FOR HIGH DATA RATES

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Abstract

Power consumption is a critical factor to most applications of Power Amplifiers, and efficient solutions exist for many purposes. Applications for high capacity wireless transmitters require that the amplifiers have a linear response over a wide dynamic range.

Class-A amplifiers have attractive functional characteristics for such applications and are still the standard solution in commercial equipment in spite of poor efficiency.

This work presents the results of an effort to combine the advantages of Class-A amplifiers with high efficiency. The approach is described along with efficiency estimates and early measurement results.

Introduction

Reducing the heat dissipation is crucial reducing the size of high-power microwave radios, as they need to be mounted close to the antenna, where heat removal is a nontrivial task. Searching a way to improve PA efficiency with manageable risk, we found that Siemens had done some interesting work using Class-A amplifiers[1]. Varying the Drain voltage of a FET amplifier according to the power level of the modulated signal, an efficiency improvement was demonstrated.

The principles for a more ambitious scheme have been discussed by Yang, Haddad and East[2]. Estimates for obtainable Power Added Efficiency in a realistic Class-A amplifier were given, promising an upper limit in the range of 24%. This is a very high figure compared with solutions applying fixed bias, where the PAPR (Peak/Average power ratio) defines the limit, frequently dropping to the range of 5%. These figures apply to the amplifier element alone.

A practical amplifier will need an efficient power supply to take advantage of the promised efficiency. This was recognized [2] by the investigation of various switch-based bias control schemes. Nera has devised a power supply solution[3] suitable for the task, which will be described in the following.

Operating principle and description of a typical modulated signal

A modulated RF (radio-frequency) signal can be parameterized as follows:

$$[1]\quad s(t) = (I(t) + j\cdot Q(t))\cdot e^{j\omega t} = a(t)\cdot e^{j(\omega t+\phi(t))}$$

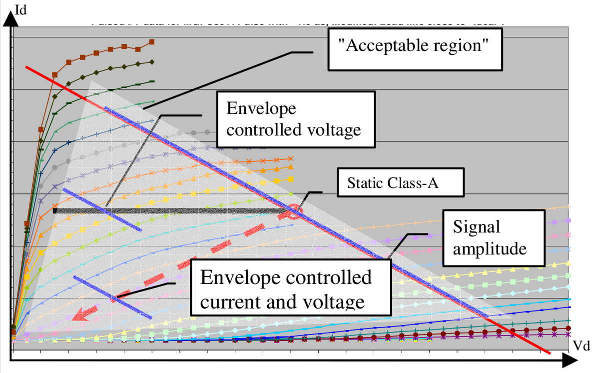

Figure 1 FET I-V curves and bias points

The complex base-band signal is $I(t)+Q(t)$ with amplitude a(t) and phase ϕ(t). The basic idea about varying the bias point of an amplifier with the signal amplitude is explained with reference to the I-V curve plot of a FET (Figure 1).

To a first approximation, we may say that the amplifier works in Class-A as long as the bias point is set such that the signal amplitude swing stays within an "Acceptable Region". A well-behaving amplifier shows little change in gain and

phase shift with change of bias point inside this region. An “Acceptable Bias Region” (ABR) can be defined once the signal amplitude is known. Amplifier performance will depend very little on the choice of bias point within the ABR. The bias point with lowest power consumption for a given ABR will be in the lower left corner of the actual ABR.
This provides a flexible framework for optimization of efficiency, as the control of the bias point can be placed with some margin in the neighborhood of an optimum location.

The use of QAM-modulation is commonplace for high-performance radios, as indicated by the use of a complex value I(t)+jQ(t) in [1]. The waveforms are generated by mapping quasi-random digital values onto a set of constellation points in an I-Q plane and applying pulse-shaping filters to restrict the bandwidths of the resulting time sequences.
From the description in [1], we can conclude that the envelope power level is

$$[2] \quad P(t)=s(t)\bar{s}(t)=I(t)^2+Q(t)^2=a(t)^2$$

It is readily seen that the bandwidth of the power level is two times the bandwidth of I and Q.

The arrangement of constellation points and the type of pulse-shaping filter may vary, but the envelope distribution shows a typical behavior, like the one in Figure 2. There is a long tail of low probability for high-amplitude states. A static biasing scheme would have to allow such amplitudes all the time. This gives an intuitive understanding of why traditional Class-A amplifiers have poor efficiency.

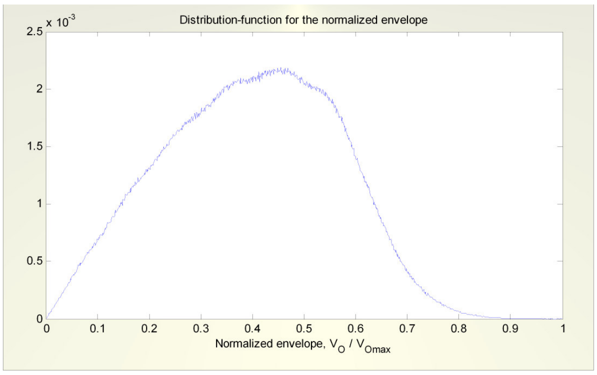

Figure 2 Probability density for signal envelope

High capacity radios work with channel bandwidths in the tens of MHz range. Dynamic biasing with such bandwidths is difficult to implement, as the amplifier will require substantial change in supply voltage and current with high frequencies.

A power supply for dynamic biasing of broadband FET amplifiers

The Class-A FET amplifier is biased on the gate and drain by feeding the bias voltages through RF Chokes as shown in Figure 3. The gate bias defines the current consumption of the amplifier, and can easily be controlled with the desired bandwidth. The drain bias sets the desired drain voltage of the amplifier and supplies the current as demanded. If voltage changes are slow, one may use off-the-shelf voltage supplies. For higher bandwidths, linear networks may be used, but such solutions suffer from poor efficiency.

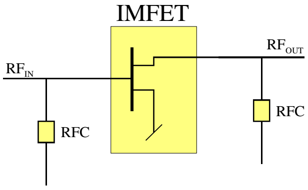

Figure 3 Biasing points

Based on the actual need, we identified a solution with very promising properties. The architecture is indicated in Figure 4, where a current source is connected to the load point in parallel with a linearly controlled voltage source (BBA; Base Band Amplifier). We find that if the current source is tuned to an optimum value of I_0. The power dissipation in the BBA can be as low as about 10% of the power delivered to the HPA.

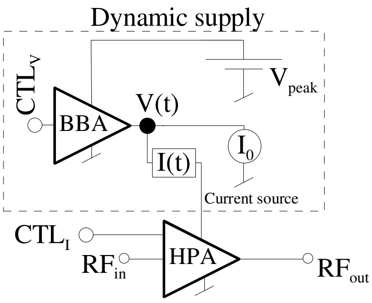

Figure 4 Efficient supply

If the current source is lossless, we might expect an overall efficiency beyond 21%. This assumes that we are able to control current and voltage very precisely as function of the signal amplitude. If we assume some reasonable efficiency for the current source and low power consumption to generate the control signals; a realistic target efficiency may be at least 15%. For the indicated PA application, this would reduce the power dissipation by a factor 3. The very attractive loss figure for the architecture rests on the fact that the BBA only deals with the current difference $I(t)-I_0$. Tuning I_0, we may bring the BBA current close to zero when there is a significant voltage difference to the supply rails, giving low power dissipation in that area. Likewise, the power dissipation will be low when the BBA voltage is close to the rails. The efficiency of this power supply under different operating conditions is quantified in Figure 5, giving the fraction available power delivered to the amplifier. A possible Bias trace is indicated. Tuning the constant current I_0 corresponds to moving the bias trace vertically. This allows optimization of the overall efficiency. The low efficiency at low voltage and current has a minor effect on average performance.

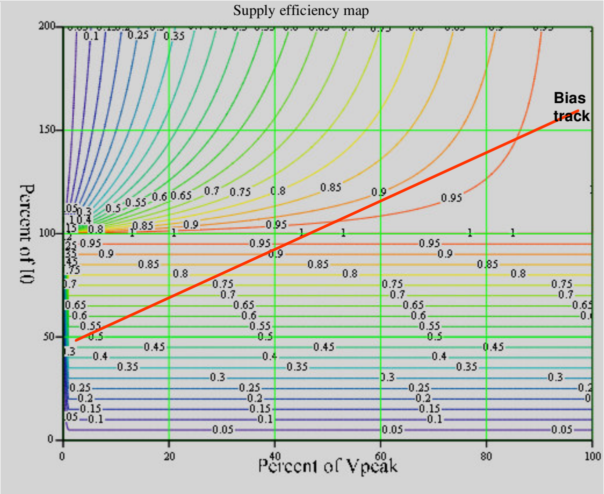

Figure 5 Efficiency of power supply

Measurements and performance

A technology test has been performed to validate the assumption that a Class-A microwave amplifier can be successfully operated with dynamic bias. The maximum bandwidth of the voltage source restricted not to exceed the channel bandwidth, resulting in an expected PA performance of 15%. Measurements showed 14%, being very satisfying. The power supply was not optimized, but the RF performance of the amplifier was thoroughly tested in a Nera technology project, showing satisfactory behavior – even under extreme climatic conditions, as indicated in Figure 6.

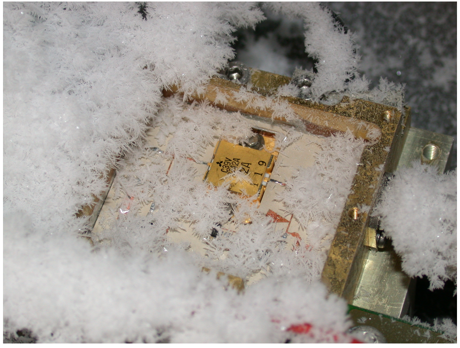

Figure 6 Cold FET in operation

Conclusion

The concept of Dynamic Biasing of broadband Class-A FET power amplifiers has been studied and proved to work close to expectation.
A solution for an efficient voltage supply to the amplifier has been identified. Different implementations have been tested, showing that the concept for improved efficiency works.

References:

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[1] C.Buoli, A.Abbiati, D.Riccardi, *Microwave power amplifier with "envelope controlled" drain power supply*, in 25th European Microwave Conf., Sept. 1995, pp.31-35

[2] Kyounghoon Yang, George I. Haddad, Jack R. East, *High-Efficiency Class-A Power Amplifiers with a Dual-Bias-Control Scheme,* IEEE Trans. Microwave Theory Tech., Vol 47, No.8, pp1426-1432, Aug. 1999.

[3] A. E. Festoe, K. Onarheim, K. M. Gjertsen, *Efficient Power Supply For Rapidily Changing Power Requirements*, Patent application WO2005041404, 2005-05-06