NEW TYPE OF CLASS A/F AMPLIFIER MMIC FOR USE IN COMMERCIAL PCS MULTIPLE MODULATION FORMAT BASE STATION POWER AMPLIFICATION

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ABSTRACT

A modified GaAs FET class-A/F amplifier provided greatly improved linear power in concurrent multiple modulation formats. The class A/F structure suppresses the 3rd and 5th order products more than 15.8 dB and 13 dB respectively, over a typical class A/F amplifier and 17.8 dB reduced 3rd order products verses a straight class A amplifier. Amp has 0.3 dB gain flatness over a 10% bandwidth.

INTRODUCTION

As a base station amplifier manufacturer, our AMPS and CDMA base stations have typically used Silicon based transistors. Silicon has been preferred due to the BJT's (or LDMOS's) ability to minimize AM/AM distortion, but the BJT's (or LDMOS's) low input impedance forces extensive hand tuning to achieve the very tight gain flatness required by base stations. Furthermore, the high emitter temperatures require expensive ceramic packaging. We modified the currently used class F matching network of a GaAs MESFET to minimize AM/AM distortion and to take advantage of GaAs FETs higher gain bandwidth product, and lower junction temperatures.

Thus, this modified class A/F amplifier improved linear power over class A and A/F, by using harmonic filters coupled with a novel feedback network. A network that allows a Silicon-like reduced AM/AM distortion. This approach allows the MESFET to be more linear under the high peak to average signals of digital modulation's non constant envelop signals, by reducing high-power shutdown. Also, it is not prone to Silicon device's strong AM/PM distortion, or class A/B linearity degradation with unequal power tones.

As base stations are moving to multiple modulation types, it becomes crucial to be able to concurrently amplify multiple modulation formats. Often the modulation format is a mixture of constant envelope carriers and non constant envelope carriers. It is crucial that the various envelop signals not distort each other, and not violate interference standards.[1] Furthermore, CDMA is susceptible to its own spectral regrowth interference.[2] This interference generation limits the system capacity, and strongly affects the cost. Thus, for PCS CDMA systems to succeed as a viable wireless product they will require inexpensive very linear power amplifiers.

The 15 dB peak to average power ratio of IS-97 make CDMA power amplifiers very difficult to design. Silicon devices are typically used due to their high peak current capability. This peak current capability plus the device's current control characteristic allows the designer to meet the linearity requirements with approximately 7-8 dB output power backoff. GaAs FETs they must typically be backed off around 11 dB, which results in very inefficient power amplifiers. GaAs FETs nonlinearity's are partly due to the Schottkey barrier diode rectifying and shutting the FET down, and non uniform modulation of Cgs. Our design approach reduces these problems.

ANALYSIS

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

One can mathematically analyze and mathematically eliminate a source of the harmonics and their associated nonlinearities. It is well known that the harmonics and their associated intermodulation products from a saturated amplifier approximately follow a tanh function. To estimate the intermodulation products one calculates the first to third order derivatives of the tanh function. We found the Taylor series coefficients to be 0 for the DC term, 1 for the f1 term, 0 for the f2 term and -1/3 for the f3 term by solving the equation.

$$y_{(t)} = \{[A(\sin w_1 t + \sin w_2 t) - 0.33A^3\{½(1-\cos 2W_1 t) + ½(1-\cos 2W_2 t) + [\cos(w_1-w_2)t - \cos(w_1+w_2)t\}\{\sin w_1 t + \sin w_2 t\}]^2\}/50$$

We find the powers (summed Taylor coefficients) of each carrier to be $(A^2)/50$ and each of the third order products to be $(((A^3)/4)^2)/50$. These coefficients (and further measurements) show that at saturated output power the third order distortion products will be 12 dB down below the carrier. While shorting out the harmonic mathematically removes the $2f_2-f_1$ and the $2f_1-f_2$ terms. In lab tests loading or shorting the reduces, but does not eliminate, the intermodulation. Thus it is well known that controlling the harmonics can partially control the intermodulation products.

The other case is CDMA modulation. Mathematically, we see that one can analyze the output CDMA signal with respect to the carriers and the harmonics of multi-tone signals to determine the power coefficients, and take a band pass transform of a signal through[3]

$$y(t)=F(x(t))\cos 2\pi ft+\theta)=z(t)\ (\cos(2\pi ft+\theta)$$ Where $z(t)=a_1x(t) +3/4a_3x^3$

If we use the Wiener_Khintchine theorem we obtain a closed form of the equation [4]

$$P_y(f)= ½B(P_0-6P_0^2 10^{-IP_3/10} + 9P_0^3 10^{-IP_3/5}) +[[3P_0 10^{(-IP_3/5)}]/2B^3](2B^2-(f-f_0)^2)$$

Where B is the bandwidth, f_0 is the center frequency. The Po/2B is corresponding to the linear output power density. The rest of the terms are caused by the nonlinearity. These terms cause the ACP. To obtain the IP3 solve:

$$IP_3=-5\log[[P_{IM3}(f_1,f_2)B^3]/[Po^3[(3(B-F_1)^3 - (3B-f2)^3]]-4.52 \text{ dB}$$

Thus one can see that CDMA under hard drive has strong 3rd order product which result in intersymbol interference and the associated BER degradation limiting of the capacity of the PCS CDMA wireless system. [5] (It is well known that the 5 ths and 7 ths also strongly affect linearity but the math is still under development.)

Traditionally, to remove the harmonics we used class F amplifiers that were class B amplifiers which had additional harmonic-suppression-networks for development of a squarer wave form which improved efficiency. Class A/F amps when operated at their most efficient point are not very linear. But when backed off they are more linear and efficient than class A amps. When additional circuitry is added they can be even more linear.

DEVICE SELECTION

A quick selection criteria for picking the GaAs device was linear efficiency. This can be accomplished by load pulling devices under two-tone, and CDMA drive conditions and see which devices have the greatest linear efficiency. We measured a number of devices and selected a TriQuint TQHiP device.

DESIGN

First, we improved the class A/F nonlinear product suppression by adding more class F elements. Class F MMIC amplifiers typically use a shunt cap at the gate and drain. These are effectively one pole filters. To improve the performance we add an additional low pass matching section. This gives us a three pole filter for enhanced distortion suppression. The three pole filter's greater rolloff with frequency was significant, and discussed below.

Second, further improvement is achieved by reducing the output impedance presented to the device. This allows for greater current for higher peak output required for PCS systems.

A third innovation, reduced the self rectification which shut the down the transistor under large signal conditions. The problem: the MESFET loose linearity as the drive power approached within 6 dB of the 1 dB compression point. So we added DC feedback which under large voltage conditions momentarily rebiases the device to beyond typical class A.

Finally, the most important innovation is the RF feedback. The RF feedback directs the drains nonlinear signal to the gate which introduces some cancellation. It is worth noting that as the nonlinear signals rise exponentially the negative feedback of the nonlinearity of course rises, introducing additional canceling. Unfortunately, this fourth innovation reduced the gain by two dB.

Our class A\F amplifier uses similar filters on the input and the output as shown in figure 1. The filter next to the device is a three pole low pass of shunt cap, series inductor, shunt cap. It slightly rounds the sharp output from pulse to pulse which suppressed the spectral regrowth. It will be shown that if the harmonics are suppressed by more filter poles, then the intermodulation components will also be suppressed more.

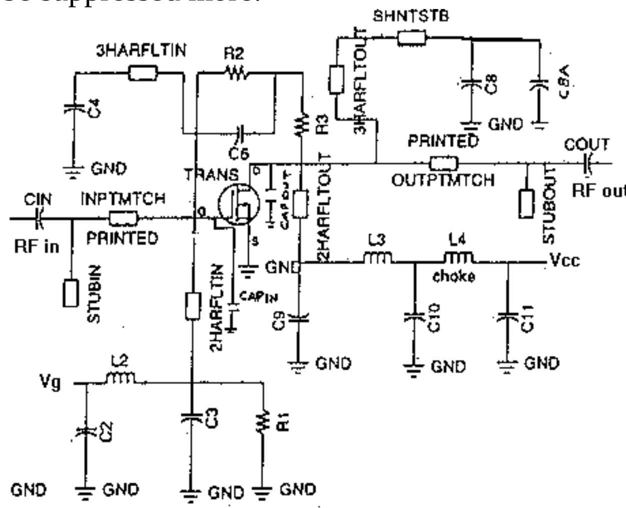

Figure 1. Simplified schematic of class A/F amplifier.

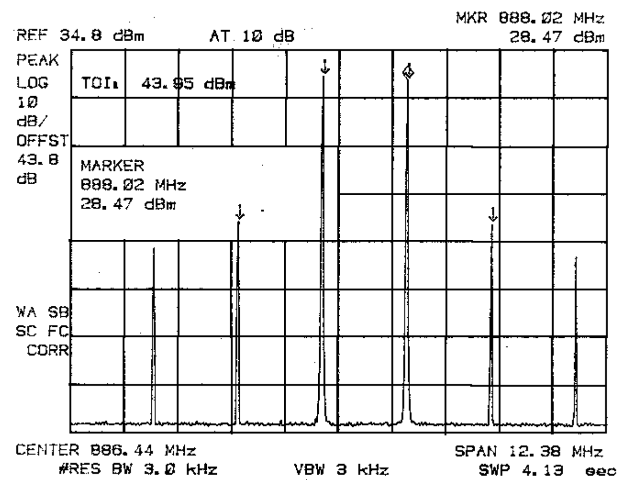

Figure 2. Intermodulation of class A/F 3.0 watt base station amplifier at 3 dB output power back-off.

A single stage GaAs MESFET class A\F amplifier was modeled, then designed. Simulation and measured data agreed thanks to TriQuint's TOM2 model. To perform the test we operated the amplifier with and without the modified class A/F feedback components. It was power matched, and was operated backed off to a half watt per tone power output. Both amplifiers were operated at the same bias power of 18 watts.

The simple, inexpensive class A/F structure using the feedback linearization suppressed the 3rd and 5th order products more than 15.8 dB and 13 dB respectively beyond that of the class A/F amplifier, see figures 2 and 3, and 17.8 dB beyond a normal class A 3rd. Figure 4 shows the modified amplifier increases the linearity and the output level where the linearity turns down.

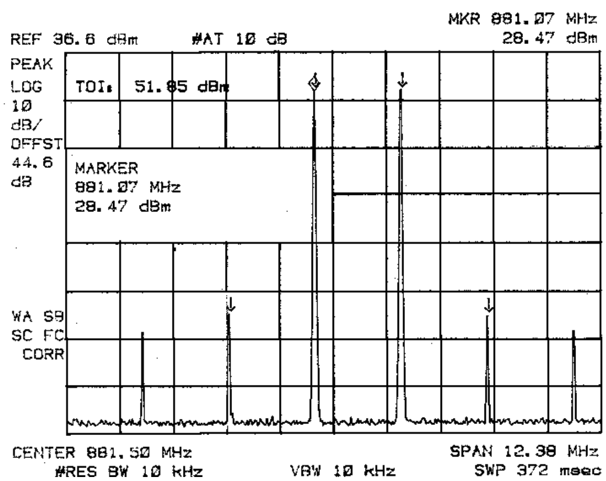

Figure 3. Intermodulation of modified class A/F 3.0 watt base station amplifier at 3 dB output power back-off.

The modified class A/F produced three dB more CDMA (IS_97) output power. The amplifier provided 0.3 dB gain flatness, with a junction temperature low enough to allow use of inexpensive plastic packaging.

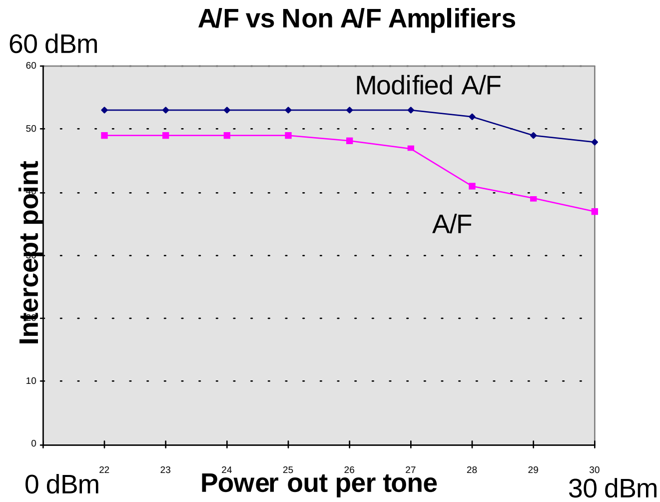

Figure 4. Modified vs non modified class A/F amplifiers Vs power out per tone.

SUMMARY

A highly modified Class A/F amplifier provided dramatically improved linear/efficiency over classes A/F, and A. This was accomplished by reducing harmonics through careful selection of harmonic filters, bias impedances and multiple feedback networks.

REFERENCE

[1] T.S. Rappaport, Wireless Communications Principles & Practice, Prentice Hall PTR, Upper Saddle River, New Jersey 1996.
[2] L. W. Couch II, Analog and Digital Communication Systems, Macmillan Pub. Company, New York, 1987.
[3] Qiang Wu, Martina Testa, and Robert Larkin. “Linear RF Power Amplifier Design for CDMA Signals” 1996 IEEE MTT-S Digest.
[4] ibid
[5] ibid