# Meeting the Needs of Cellular Dual-Mode (EGPRS/3G) Power Amplifiers with a Unique J-PHEMT Process and Novel Control Architecture

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*Abstract* — **Based upon a unique Junction-PHEMT device, a novel method of providing high efficiency PA power control for variable envelope modulation schemes is demonstrated for EDGE and WCDMA. The method of control allows for substantially higher efficiency levels under typical handset operating conditions than those of conventional linear power amplifiers, on a par with polar loop solutions, whilst avoiding the necessity for complex control loops. An immediate benefit of the approach includes the ability to add EDGE front-end capability to a GSM handset without incurring a significant size or component cost impact. Furthermore, the method of control aids the future prospect of single transmit strip multi-mode configurations (GSM/EDGE/WCDMA) in order to achieve considerable size and cost advantages.**

## I. Introduction

Power amplifiers for GMSK modulation, used extensively in multi-band handsets to date are relatively simple to implement and provide efficiencies of up to 60%[1]. This is due to the fact that the constant envelope modulation scheme permits PA operation in the saturated region. Figure 1 illustrates the output power and efficiency performance of a Sony Quadband J-PHEMT PA across the GSM850 and EGSM900 frequency bands at a supply of 3.2V and is considered amongst the best in class. The PHEMT exhibits several attractive characteristics compared to alternative PA technologies, such as high Gm at turn-on (good for saturated PA) and a linear Gm/bias characteristic (good for linear PA)[2]. The ability to operate at low supply voltages keeps the technology future-proof. A linear WCDMA PA based upon the Sony J-PHEMT process has been previously reported [3]. With an efficiency of 47% and ACPR performance well inside the system specification limits, it represents one of the highest performance cellular power amplifiers reported.

Operation with non-constant envelope modulation schemes, such as those associated with EDGE (3π/8-8PSK modulation) or WCDMA (HPSK modulation), traditionally require the PA input power to be backed off by several dB into the linear region such that AM-AM and AM-PM distortion is reduced as the input signal peaks with the modulation envelope. Operation within the linear region comes at the price of lower efficiency. Also, a variable gain amplifier (VGA) is necessary in order to adjust the input power to the PA. Such a function can consume 20-50mA -further degrading the efficiency and adding to the chipset size and cost.

Whilst substantial progress has been made on cellular basestations, most of these efficiency enhancement techniques are unsuited to handsets due to excessive component count, size and cost. Thus, significant effort has recently been devoted to applying effective but simpler schemes for handset use. In particular, the demand for efficiency enhanced EDGE solutions has been a main focus. Linear back-off PAs have been used in the first commercial EDGE enabled handsets. However, the narrow modulation bandwidths of EDGE can permit the use of other techniques such as polar loop [4].

Efficiency enhancement techniques based upon polar loop have been proposed for GSM/EDGE handsets [5], however these implementations are typically associated with a high level of complexity and do not allow an elegant migration path to 3G. Consequently, most current dualmode RF architectures are based upon multiple transmit strips with fundamentally different architectures for GSM/EDGE and WCDMA. Furthermore, the efficiency potential of polar loop solutions for EDGE is often not fully realised due to current consumption requirements within the correction loops.

In order to address all GSM, EDGE and WCDMA requirements, a novel scheme based upon a direct modulation architecture was developed which permits optimum GSM efficiency whilst allowing enhanced EDGE and WCDMA performance compared to conventional multi-mode linear PA solutions, maintaining architectural compatibility for all modes.

## II. Saturated And Linear PA's Based Upon Drain Control

Although several methods of GSM power control exist, open-loop supply regulation has been used extensively due to its simplicity and well controlled characteristics.

Figure 2 illustrates the basic concept of power control using supply regulation. Due to the fact that the output power from the PA has a predictable relationship with supply voltage over temperature and frequency, power detectors and couplers can be avoided, thus saving cost and reducing size. Fundamentally, the method of control relies upon the supply voltage limiting the RF output voltage and is thus normally only valid for constant envelope modulation schemes, such as GMSK, which are insensitive to the gross AM nonlinearities associated with this technique. Tight grouping of the output power versus Vramp curves over temperature and frequency ensure that the power accuracy window can be met with comfortable margin over the entire GSM control range.

Conventional linear power amplifiers for non-constant envelope modulation schemes, such as those associated with EDGE and WCDMA, avoid supply regulation due to the fact that envelope distortion is normally inevitable as the supply voltage is reduced. Instead, power control is achieved by means of varying the input power to the PA by use of a VGA (variable gain amplifier). However, use of a VGA has an impact upon current consumption, die size and the ability to meet the stringent wideband noise requirements for GSM and EDGE.

Detailed simulation work showed that the linear or small-signal gain of a 3 stage J-PHEMT PA exhibited a strong dependence upon drain supply voltage, Vdd. As drain voltage is reduced, the gain also decreases to the extent that over 25dB of monotonic gain control can be achieved between 0.5 and 3.5V drain supply (approx 50dB from 0-3.5V). Figure 3 illustrates the measured gain versus Vdd of a practical 3 stage PA. As long as the gain decrease with drain voltage is greater than the decrease in output power due to voltage clipping ($\propto V_d^2$) then it is possible to use drain voltage control for a linear PA. Figure 3 also shows that the PA gain roll-off is faster than the potential reduction in final stage output power resulting from supply voltage clipping, thus maintaining the back-off margin (approx 5dB) set at maximum power.

By making use of the gain/drain voltage characteristic possible with the J-PHEMT process, a linear PA has been demonstrated based upon drain regulation and has been characterised for both EDGE and WCDMA modulation schemes. Fundamentally, this technique relies upon the PA gain rolling off faster than the output voltage clipping such that the peak-mean power ratio, or back-off, is maintained over the required control range.

## III. Drain Controlled Linear PA Results

Dealing with the EDGE modulation at first, the 3 stage GSM PA was re-biased closer to class A and the input power reduced by around 10dB such that the output power reduced to 28.5dBm in order to meet the EDGE Power Class E2 specification of 27dBm at the antenna (assuming approximately 1.5dB loss between the PA and antenna port). The PA is now operating outside compression with sufficient margin for the 3.5dB peak-mean power difference associated with the EDGE modulation scheme. At the nominal supply voltage of 3.2V (after the drain PMOS device), the EVM, ACPR and efficiency were measured, whilst keeping the existing GSM matching circuits. An efficiency of 23% resulted, with EVM and ACPR (400KHz offset) inside specification: 4.3% and –56dBc respectively. The drain voltage was then reduced and modulation performance, spectrum and current consumption monitored. Figure 4 illustrates the resulting EVM and ACPR performance across the operating control range (5-28.5dBm). EVM remains below 5% and ACPR well inside specification (–54dBc (@400KHz or –36dBm) over the complete control range.

Taking a complete power amplifier module with integrated power control, the output power and efficiency were measured against Vramp. Figure 5 illustrates the efficiency and output power performance over the control range whilst keeping inside the EVM and ACPR limits. The smooth output power/Vramp characteristic permits a well behaved loop characteristic.

Over temperature, the characteristic also proved to be well behaved with less than +/-1dB variation from –20 to +85°C, Figure 6. The low variation over temperature and flatness across frequency band also make it possible to eliminate the output coupler and power detector circuits which are often used for linear EDGE PA solutions, such that the method of open-loop drain control is used for both GSM and EDGE modes. Furthermore, it was also possible to remove the isolator associated with other linear PA solutions. Measured VSWR variations of 3:1 at the PA output were found to degrade EVM by around only 2% at worst case phase.

Receive band RX noise was measured at 10-30MHz offset from carrier and found to meet the requirements with a value of –84dBm in 100KHz at 20MHz offset.

This method of power control permits significant improvements in efficiency to be achieved at typical handset operating powers (10-20dBm) compared to the standard linear PA. Performance under typical operating conditions is not substantially different to polar loop solutions, whilst the need for additional complex control loops is avoided. The relative improvement in efficiency is brought about by the fact that the reduction in drain voltage results in a corresponding reduction in drain current. Figure 7 illustrates the supply current consumption variation with output power for the drain controlled linear PA compared with the conventional approach of external VGA prior to PA I/P and fixed supply voltage. Whilst consumption is similar at full output power, substantial savings are incurred in the typical handset operating region of 10-20dBm.

The efficiency improvements brought about by drain regulation for linear PA can be further exploited by use of DC-DC converters instead of the conventional PMOS supply regulator. Table 1 illustrates the efficiency comparisons between the proposed drain controlled linear PA and conventional fixed supply linear PA with VGA (assuming 20mA consumption) and at 3 different output powers. For the drain controlled linear PA, 3 cases are

| Output Power Level | Measured Conventional Linear PA (assuming 20mA VGA consumption) | Measured Linear Drain Control with PMOS Regulator for power control | Linear Drain Control with Ideal DC-DC Converter power control based on measured power vs. supply voltage characteristic. | Linear Drain Control with fast DC-DC converter (ideal) for envelope tracking and power control, based on simulation. |
|---|---|---|---|---|
| 28.5dBm | 21.6% | 23% | 23% | 32% |
| 20.0dBm | 6.7% | 10.0% | 20% | 28% |
| 10.0dBm | 1.1% | 3.5% | 17.5% | 24.5% |

**TABLE I**
**DUALMODE (GSM/EDGE PA) EFFICIENCY COMPARISONS BETWEEN CONVENTIONAL LINEAR PA AND DRAIN CONTROLLED J-PHEMT PA WITH EDGE MODULATION**

considered: conventional PMOS supply regulation; regulation based upon an ideal DC-DC converter and envelope drain modulation based upon a fast DC-DC converter. The latter requires the use of AM-AM correction loops, thus achieving the improved efficiency at the expense of greater complexity.

A high band 3 stage GSM PA was also measured with the WCDMA modulation scheme within the European UMTS frequency band whilst using the drain regulation method. ACPR performance could be maintained over the top 10-15dB of control range (Figure 8), thus relaxing the requirements on the high dynamic range TX VGA required for WCDMA (total of 90dB range is necessary). As with the case of EDGE, significant efficiency improvements could be realised compared to conventional control.

## IV. GSM/EDGE/WCDMA RADIO SOLUTION

Use of this method of PA control in all three modes (GSM/EDGE/WCDMA) substantially eases the VGA requirements within a multi-mode direct modulation transceiver architecture. This relaxation reduces overall current consumption and helps achieve the stringent receive band noise requirements, thus assisting with the realisation of single strip multi-mode transmit architecture.

## V. CONCLUSIONS

A proposed method of power control, based on drain regulation, has been demonstrated for GSM, EDGE and WCDMA. Whilst permitting the handset manufacturer to achieve the optimum cost, size and performance, EDGE front-end capability can be added with relative ease. Furthermore, the method of control has been shown to greatly improve efficiency, and thus talk-time, compared to conventional linear power amplifiers. The complexity and size of polar loop type solutions is avoided whilst maintaining most of the key benefits.

Finally, with the suggested use of output match/transistor switching, it is possible to produce a front-end solution based upon the use of a single PA (low band and high band) with a common method of power control.

## ACKNOWLEDGEMENT

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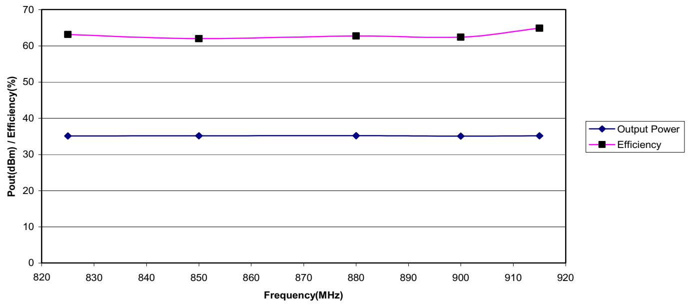


**Figure 1 GSM PA Characteristic at Low-Band (824-915MHz)**

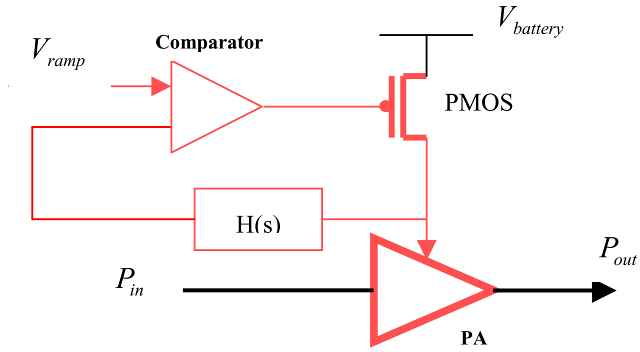


**Figure 2 Power Control based upon supply regulation**

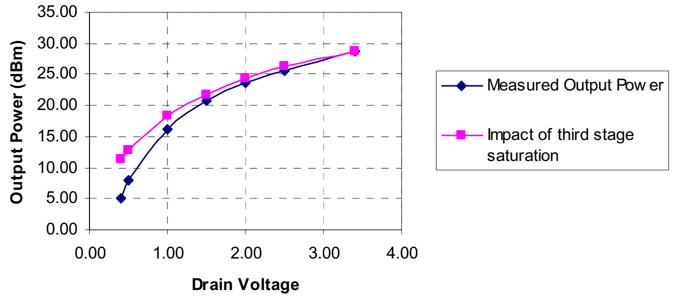


**Figure 3 PA Gain vs drain characteristic and Impact of final stage compression on back-off margin**

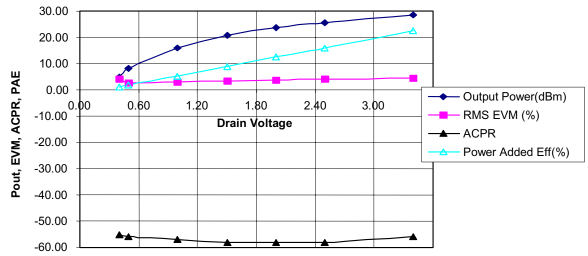


**Figure 4 EDGE Mode: Characteristics versus drain voltage**

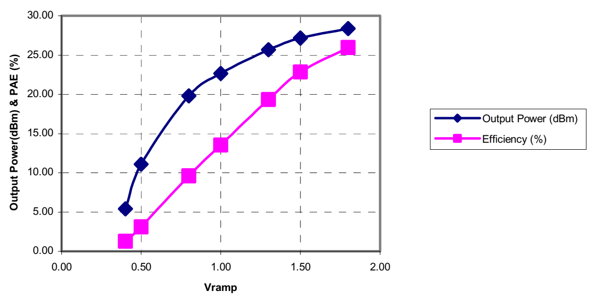


**Figure 5 EDGE Mode: Power Control and Efficiency Characteristics using GSM control IC.**

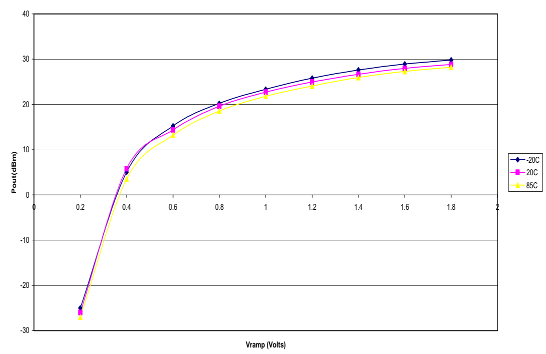

**Figure 6 EDGE Power Control/Vramp Characteristic over Temperature (-20 to +85°C)**

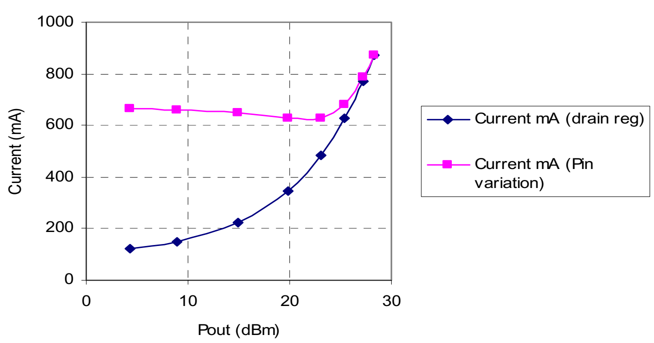


**Figure 7 Consumption of Linear PA based on drain regulation compared to conventional approach of Input power adjustment**

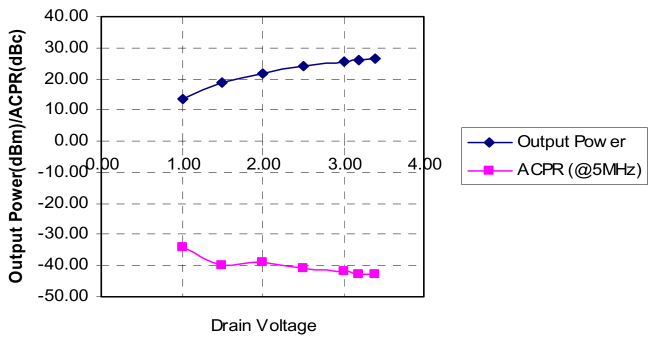


**Figure 8 High Band GSM PA in WCDMA Mode at 1920MHz: ACPR and Output Power Versus Drain Voltage**