RF Power GaAs for Wireless Infrastructure Markets

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Abstract

GaAs technologies have seen broad acceptance for low power (<1W), cellular handset RF power amplifier applications. RF high power GaAs (>10W) has, until recently, been used mainly for military, peripheral and niche market places. With the advent of 3G cellular communications, RF high power GaAs technologies are beginning to enter the mainstream of the wireless communications markets. Up to now, the RF linear power amplifier technology of choice has been a silicon-base FET technology, LDMOS (Laterally Diffused Metal Oxide Semiconductor). Will RF high power GaAs become a major player in the mainstream, high-volume markets? What effect will GaAs have on the future of communications infrastructure technology? Recent improvements in the efficiency of RF high power GaAs and state-of-the-art linearity attributes of LDMOS makes this race "too close to call".

INTRODUCTION

LDMOS vs. GaAs? This is the question being debated by every base station power amplifier design team around the world. Power GaAs and LDMOS manufacturers continue to make advances in the overall peak power capability and gain of the RF power transistors. This paper will describe recent improvements in the efficiency and linearity of RF power devices. In addition to the raw RF performance tradeoffs of power GaAs vs. LDMOS, this paper will discuss influential industry market trends, system level tradeoffs, and high volume semiconductor manufacturing requirements which need to be understood in the overall decision making process of which technology to use.

RF POWER SEMICONDUCTORS, A LITTLE HISTORY

In the 1990's, high voltage LDMOS technology changed forever the way RF power amplifiers were designed. Initially designed for higher gain and lower costs, power amplifier (PA) designers were pleased to find that LDMOS also came with superior linearity, perfectly suited for the linear cellular modulation formats of the mid '90's such as TDMA and CDMA, and later EDGE and W-CDMA. Although still widely used in Japanese cellular applications, outside of Japan power GaAs was used mainly in driver or class A pre-driver stages of an RF PA. As base station manufacturers were driven for significant year-on-year price reductions and as global infrastructure volumes grew, LDMOS with its overall performance and lower cost basis became the technology of choice over power GaAs and Silicon BJTs for linear RF power amplifiers. In fact, what used to be the largest section of the GaAs power transistor market - devices greater than 10 watts - incurred a significant loss in market share due to LDMOS. Despite this market share erosion by LDMOS, the cellular/PCS remains the leading application for GaAs power transistors (Table I) [1].

TABLE I
GALLIUM ARSENIDE POWER TRANSISTOR BY APPLICATION
WORLD SERVICEABLE AVAILABLE MARKET, 1999

Application	Value ($millions)	Share
Cellular/PCS	93	38%
Broadcast/Radio	0	0%
Radar	12	5%
Military	5	2%
Avionics	7	3%
Satellite	44	18%
Point to Point (licensed)	34	14%
ISM	17	7%
LMDS	17	7%
Others	15	6%
Total	246	100%

Source: Allied Business Intelligence, Inc., 2000

MAINSTREAM MARKETS FOR POWER GAAS

Led by Japan and Europe, new third generation (3G) products are being designed around the world. What better opportunity for GaAs power transistors to compete against LDMOS then a new application at 2.11 – 2.17GHz? What once was considered an advantage of GaAs over LDMOS was GaAs technology's capability to operate up through the microwave frequency range. However, multiple generations of LDMOS development proved successful in high power RF at 2GHz, just in time for mass production of 1.8 – 2.2GHz system deployments. Whether driven to fill unused capacity in their GaAs fabs, or lured to the growing and lucrative cellular infrastructure market, RF power GaAs manufacturers aggressively priced themselves at a competitive $/Watt (reducing prices by over 50% within a year's time frame) and have their sights set on the high-volume mainstream markets at 1.9-2.2GHz. The battleground for LDMOS vs. GaAs is clearly 3G.

Decisions of the ITU in 2000 has set the stage for battleground #2 of the LDMOS vs. GaAs saga. Most of the world, led by Europe, announced the allocation of the 2.52 – 2.67GHz band for 3G expansion. Operation will commence by 2005. More recently, the US FCC announced consideration of both the 1.710 - 1.885 GHz and the 2.52-2.67GHz bands for 3G in the US. Many factors exist in the US which could impact the selection of the 3G band for the US at 2.52 - 2.67GHz, however, the main implication is that the next LDMOS vs. GaAs battleground could very well be 2.52 - 2.67GHz. And if that is the case, GaAs would have a significant advantage due to the frequency of operation. However, if 1.710 - 1.885GHz is chosen, then LDMOS will have a considerable advantage due to its wide acceptance for use in existing US PCS1900 and GSM1800 bands. LDMOS can operate at 2.6GHz, far higher than previously thought only 5 years earlier, with good gain. The magical performance barrier for LDMOS at 2.6GHz is EFFICIENCY.

As the market demand for bandwidth increases, operating frequencies will also have to move up. Historically this demand was driven by voice as cellular penetration grew around the world. In the future, this will be IP driven, increasing the market's demand for data bandwidth. That usable bandwidth must be reliable and cost-effective. Today this usable bandwidth for new, high-traffic reliable wireless communications is focused from 1.7GHz up to 6GHz (Table II).

TABLE II
NEW WIRELESS INFRASTRUCTURE MARKET FREQUENCY SPECTRUM

Frequency Band	Name	Primary Use
2.11 – 2.17 GHz	3G	Voice + Data
1.710 – 1.885 GHz	3G Expansion, US only	Voice + Data
2.52 – 2.67 GHz	3G Expansion Europe and maybe US (current MMDS spectrum in US)	Voice + Data
3 – 6 GHz (tbd)	4G (still to be defined)	Data

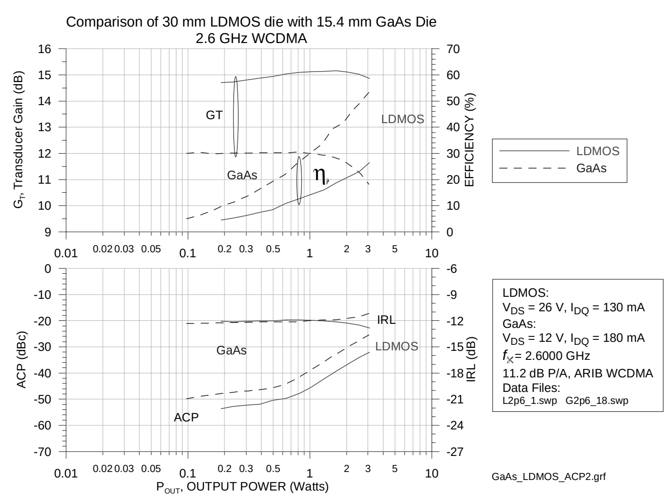
There has been, to date, no official definition of 4G. 4G will operate at 10x or greater data rates then 3G. One assumption that can be made is that based on this data requirement, 4G will need to operate at frequencies above 3GHz. This is where sufficient spectrum bandwidth is available. Above 3GHz, semiconductor device physics is relatively clear, GaAs will be the technology of choice for high power RF.

LDMOS & GaAs Performance

Linear RF power amplifiers are very inefficient due to the fact that you need to operate RF power transistors backed off from the 1dB compression point. This drives mechanical and hardware overhead to compensate for thermal inefficiencies leading to significant increases in the overall cost of the PA. Therefore, making incremental improvements in RF transistor efficiency is an extremely important factor in the size and cost of a PA. The value of RF power GaAs lies in its inherent efficiency.

As mentioned earlier, the magical performance barrier for LDMOS at frequencies above 2.2GHz is efficiency. Figure I shows a comparison of a Motorola's 30mm 26V LDMOS die and a newly developed Motorola 15.4mm 12V PHEMT GaAs die evaluated at 2.6GHz with a single carrier W-CDMA modulated signal. For a given ACP level, the GaAs device performs at nearly 10 points better in efficiency despite LDMOS's good gain and linearity. There is a clear advantage of GaAs over LDMOS at 2.6GHz

FIGURE I
COMPARISON OF 10W LDMOS VS. GAAS DIE AT 2.6GHZ W-CDMA



At lower frequencies, the linearity vs. efficiency gap narrows. Power GaAs transistor efficiency (at 2.1GHz) is on par with LDMOS or at best, up to 5% better in efficiency than LDMOS. This depends greatly on the required ACP value. GaAs and LDMOS manufacturers are both making great strides in increasing the peak power capability of their product offerings [2], [3]. As 3G systems deploy and production volumes start to ramp-up, OEM's will be aggressively pushing for lower cost RF power amplifiers. The overall tradeoff between linearity, efficiency, cost, manufacturability and consistency will be scrutinized intensely. Subsequent generations of LDMOS are in development with the promise of improved efficiency, however, similar claims are being made by power GaAs manufacturers too. The ability of GaAs to become a major player in 3G linear power amplifiers will depend on the differentiation of improved performance due to efficiency over LDMOS and proof of high-volume, consistent RF performance. GaAs will also have to continue to be aggressively priced to realistically compete with LDMOS.

SYSTEM LEVEL TRADEOFFS

In addition to improving the peak power capability of RF power GaAs, manufacturers are also pursuing advancement of the GaAs-based heterostructure FET (HFET) for improved gate-to-drain breakdown voltages which would enable operation at 20V+ [3]. High voltage (26-28V) GaAs transistors would then be on a level playing field with LDMOS in terms of operating voltage. Improved linearity characteristics of HFET GaAs were achieved as drain voltage was increased [3]. Although improved linearity due to increased operating voltage was seen, the linearity of LDMOS is still superior [4].

So will the inferior linearity characteristic of RF power GaAs be it's Achilles heel? Perhaps not. Linear RF power amplifier manufacturers still have the ability to design to a -35dBc adjacent channel power ratio (ACPR) value though most design to a –40dBc value. At the base station systems level, advancements in linearization improvement may in effect make the device linearity characteristic less of an issue. If digital circuit designers can improve the distortion externally to the power amplifier by –15 to –20dBc, simplified (less peak power, lower cost) RF power amplifiers operating at –35dBc ACPR may suffice.

HIGH VOLUME MANUFACTURING REQUIREMENTS

Is RF power GaAs ready to be a mainstream component for the high-volume infrastructure industry? OEM's today are manufacturing and/or consuming thousands of linear power amplifiers per week, not hundreds per week. Quality and consistency of product is today just as important as performance. The wireless communications market demands it. Small, niche GaAs manufacturing operations will have a tough time in this regard.

The advantage obviously goes to the large GaAs manufacturers who have the breadth of technology and manufacturing capability to service this market. These capabilities can only come from the volumes driven by the wireless handset market. GaAs wafer costs (PHEMT or HBT) today are still 2-3x higher than equivalent LDMOS costs. To service the RF high power GaAs market it will be necessary to couple, from a manufacturing standpoint, with the RF low power GaAs business to drive wafer costs down. To not do so would result in extremely expensive and uncompetitive RF high power GaAs.

The same is true for LDMOS manufacturers. Unarguably, an underlying reason for the success of Motorola, the leader in high voltage LDMOS for the wireless infrastructure market, is due to the economies of scale of processing LDMOS wafers in large, MOS-based wafer fabs. The same must be true for RF power GaAs.

High volume manufacturing is not only defined by wafer fabrication manufacturing. High power RF semiconductor costs, quality and consistency are heavily influenced by the back-end manufacturing, RF assembly and test. Due to the high cost of ceramic packaging for RF semiconductors, economical package development is also a key factor. Improvements in die attach (especially challenging for power GaAs products due to the thin die required for thermal stability) and wirebonding are essential for pushing the manufacturing roadmaps to achieve performance improvements while also improving product consistency and reducing costs. A focus on package and manufacturing costs (front-end and back-end) are required to deliver the average selling price (ASP) reductions demanded by the industry. These have been averaging 15-20% per year.

CONCLUSIONS

RF power GaAs and LDMOS manufacturers continue to make advancements in peak power capability, efficiency and linearity. GaAs is becoming a larger player in the mainstream high-volume markets, the bulk of which is in the 1.7 – 2.6GHz frequency range. Volumes and industry expectations are high, but if GaAs continues to deliver improvements in efficiency, linearity, cost, manufacturability and consistency of performance, then, yes, GaAs will become a major player in 3G markets.

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REFERENCES

[1] A. Fuertes, "Wireless Power Devices, Transistors, Ics, and Power Modules, Strategies, Technologies and Trends, World Market to 2004", Allied Business Intelligence, pp. 22-32, 2000.

[2] K. Inoue, et. al, “A 240 W Push-Pull GaAs Power FET for W-CDMA Base Stations”, IEEE MTT-S Digest, pp.1719-1722, 2000.

[3] K. Matsunaga, et. al, “A Low-Distortion 230W GaAs Power FP-HFET Operated at 22V for Cellular Base Station”, IEEE IEDM Technical Digest. 2000.

[4] A. Rabany, et. al, “Characterization of 125 Watt Single-Ended Power Discrete LDMOS Device for W-CDMA Base Station Amplifier Application,” Wireless Systems Design, Nov. 2000