Trends and Opportunities for Gallium Arsenide Semiconductors in Handsets

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Keywords: GaAs, handsets, power amplifiers, switches, HBT

Abstract

Demand for GaAs semiconductor products is largely driven by the handset industry. Specifically within the handset space, GaAs products are most prolific in power amplifier (PA), switch, and small-signal amplifier applications. The PA segment drives roughly ninety percent of this demand, thus tending to be the most competitive segment for compound semiconductor products in handsets. During the last several years, GaAs based PAs have gained market share over silicon competition due to several factors. In this paper, these factors are briefly discussed. Dramatic changes in cost and integration are noted as the adoption of GaAs based PAs has continued to increase. Next, this paper reviews future handset trends that will drive front-end component requirements. Finally, the next series of critical success factors necessary to drive GaAs demand growth are identified.

INTRODUCTION

Ten years ago, the majority of power amplifiers in mobile handsets were built using discrete transistors. These were silicon based bipolar and MOS transistors that operated from either 4.8V or 6V power sources. These solutions required many external matching and biasing components. Around 1996, a leading handset provider dropped their battery system down to 3V (relying only on a stack of two 1.5V battery cells) while simultaneously requiring an integrated component power amplifier. These requirements led the drive for new technologies that offered higher efficiencies and output power at lower supply voltages, as well as technologies that could better provide single chip integration of a multi-stage amplifier. Performance wise, gallium arsenide HBT and MESFET amplifiers were ideally suited to these new requirements. Specifically, the HBT required only a single polarity power supply for implementation, while its depletion mode MESFET counterpart required a negative voltage for biasing. The lower knee voltage of GaAs HBT transistors as compared to silicon based solutions allowed this technology to deliver the required amplifier output power and improved efficiency for this 3V power supply requirement.

Another advantage of GaAs based technologies over their silicon counterparts is better amplifier linearity. For GSM (non-EDGE) systems, a non-linear PA is adequate. But newer handset communication standards such as TDMA and CDMA began ramping in the mid 1990's, both requiring linear amplification.

These three requirements, lower operating voltage, more integration and modulation systems that require linear signal amplification, opened the door for GaAs based amplifier solutions. Additionally, by the early 1990's HBT reliability was proven to be adequate to support handset applications. [1]

By the late 1990's, GaAs semiconductors had taken over more than half of the handset PA slots, with silicon LDMOS and bipolar accounting for the rest. Each subsequent year thereafter, GaAs market share has steadily increased to it's current level of about 80%. RFMD's current estimate of the PA market share split by semiconductor technology is shown in Figure 1.

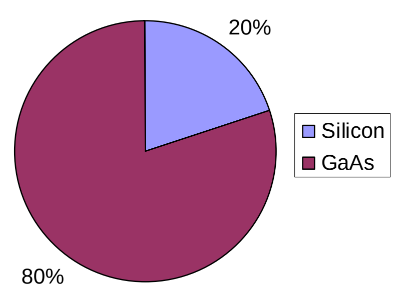


Figure 1 PA market share estimate by semiconductor technology for 2004 (source: RFMD)

COST CHALLENGES

Based on performance requirements, GaAs HBT established itself as the preferred technology for handset power amplifiers during the latter half of the nineties. At that time, the biggest challenge facing GaAs PA products was cost. Hampered by traditionally low volumes – driven only by space and military applications – costs for a single millimeter of GaAs (roughly the die size for a single-band PA MMIC) was on the order of $2.00. A decade ago, most

HBT processing was performed on 3” wafers. High-volume proliferation of GaAs HBT products was reliant on costs being significantly reduced. Around 1998, high volume fabrication of 4” wafers was common place and over the last couple of years, several foundries are now qualified and are running high volume on 6” wafers. This larger wafer size, coupled with a tremendous increase in volume, has allowed the cost of a millimeter of GaAs to drop by an order of magnitude during the last decade.

HANDSET TRENDS

Needless to say, the handset feature set has changed tremendously during the past decade. Just to name a few features, the addition of MP3 players, cameras, FM radios and the onset of large high resolution color displays are obvious to all users. Less obvious are the architecture and component changes within the handset. Many users just know handsets are getting smaller and more feature rich. Ten years ago, all handsets were single band, in other words they only supported a single frequency band. During this time period, regardless of second generation (2G) modulation standard, GSM, TDMA or CDMA, handsets were typically *either* low-band or high-band. As the handset user base grew dramatically over the next couple of years, carriers quickly added capacity to both their low and high-band spectrum. To allow more capacity flexibility, carriers insisted on newer phones supporting both frequency bands. For GSM, this transition to dual-band began in about 1997 and was virtually completed by 2001.

By this point in time, some of the dual-band phones supported one European frequency band and one American band. These initial “world” phones suited international travelers nicely, allowing them to use the same handset on multiple continents. Unfortunately, these handsets could not support multiple frequency bands within the same region. So, today’s generation of GSM world phones now support all four of the major frequency bands: GSM 800/900 and DCS 1800/1900, allowing geographic and capacity flexibility. Figure 2 shows a simplified block diagram for the transmit section of a quad-band GSM handset. All told, approximately ninety percent of today’s 2G handsets are multi-band.

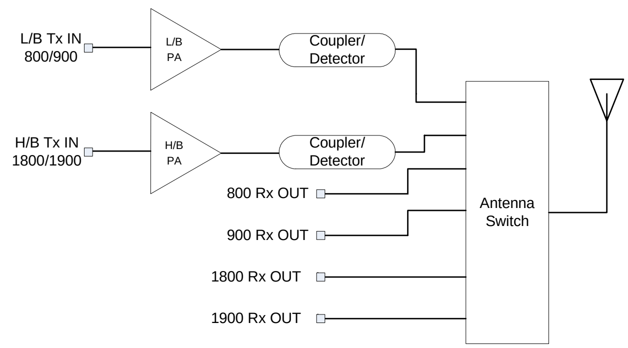


Figure 2 Simplified block diagram of a quad-band GSM front-end section

In addition to the proliferation of multiple frequency bands, there has been a transition to new modulation protocols that support higher data rates, such as EDGE (2.5G) and WCDMA (3G). These advanced systems require linear amplifiers (or polar modulation) which has translated into more stringent PA requirements. Without question, during the next one to two years, the fastest growing market segments within handsets will be in the EDGE and WCDMA areas. The majority of handsets supporting WCDMA will also be backward compatible and able to support EDGE or GMSK operation. This backward compatibility will drive new multi-mode requirements. End-users will rely on this multi-band/multi-mode (MB/MM) functionality as carriers continue to build out their 3G infrastructure. Additionally, these MB/MM systems will increase the demand for low loss rf switches. In the past, PIN diodes have owned the dominant share of this market, but now GaAs pHEMT switches are beginning to gain some share in this fast growing application. In the rf system space, the challenge is to provide this MB/MM functionality while continuing to drive down the overall cost of the handset, thus helping to keep the market growing at a steady pace.

COMPONENT TRENDS

Handset providers require these multiple band rf solutions to shrink in both size and cost. Smaller size means more integration. As mentioned previously, PA MMICs took over for discretely matched power transistors around 1996. These single-band MMIC solutions reigned throughout the decade and then modules began dominating after 2000. Consistent with the multi-band handset trend, these low cost modules were typically dual-band for GSM applications. The focus of these first modules was to significantly reduce the number of components in the PA section, while also achieving some size reductions. Initial dual-band PA modules were about 150mm^2 in size. Figure 3 shows a non-encapsulated single-mode (GSM) dual-band

PA module. This first generation PA module began shipping in high volume in 2000, with volume peaking around 2002. The total GaAs HBT die area for this solution is about 2.4mm^2.

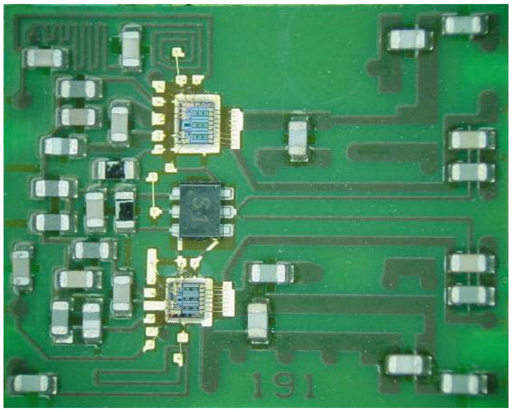
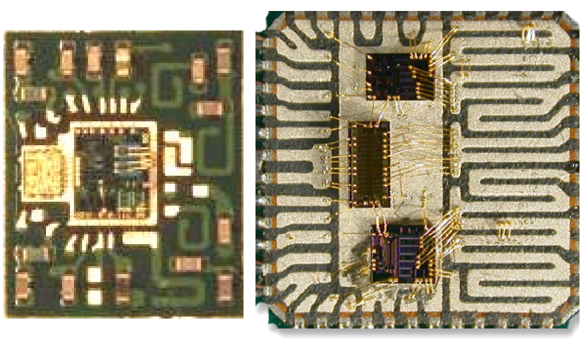


Figure 3 First generation dual-band PA module measuring 150mm^2

Second generation modules focused on significant size reduction, while also increasing the amount of integration. Figure 4 shows a picture of two PA modules that are shipping in high-volume today. The size of the module in Figure 4a is 30mm^2, about seventy five percent smaller than its predecessor. In additional to being smaller, this module delivers dual-mode (GSM and EDGE) quad-band power while also integrating the power detector in the module. The module in Figure 4b is slightly larger, but it completely integrates all passive components on die or as part of the package, eliminating the need for any SMD components.



(a) (b)

Figure 4 Second generation PA modules, (a) quad-band GSM/EDGE measuring 30mm^2 and (b) quad-band GSM measuring 49mm^2

Table 1 shows the side-by-side feature set and bill of materials comparison between these three modules. The increased feature density of the second generation modules were mainly achieved through integration on the GaAs HBT die. In addition to the traditional amplifier integration, the smaller modules integrate many passive matching components on the GaAs die. For the module shown in figure 4a, the GaAs die also provides an integrated power coupler and detector for each band. Previously, handset designers would implement the power detector discretely, consuming an additional 30mm^2 of phone board area and adding 6-10 more components. Due to increased integration, GaAs die area increased 15-25% in these 2nd generation modules.

TABLE I

FIRST AND SECOND GENERATION PA MODULE COMPARISON

Feature	**1st Generation**	**2nd Generation**	
		(a)	(b)
Description	Dual-band GSM	Quad-band GSM/EDGE w/ Integrated Power Detection	Quad-band GSM/EDGE w/ PowerStar™
Module Size	150 mm^2	30 mm^2	49 mm^2
Die Size	2.4 mm^2	3.0 mm^2	2.7 mm^2
SMD's	29	15	0

FUTURE SUCCESS FACTORS AND TRENDS

Cost effective integration capability will be the key success factor for any PA semiconductor technology going forward. Effective integration within the PA section helps to address three major problems for handset suppliers:

1) Size reduction
2) Cost reduction
3) Ease of implementation

More and more, die size is being driven by passive component integration. Focusing on integrated capacitors and inductors with higher capacitance density and quality factors, respectively, is very important.

Next generation PA modules will integrate the complete transmit functionality shown in Figure 2. The six throw rf switch shown in the figure will have to be integrated into the module in both a size and cost competitive manner. As mentioned previously, PIN diodes have been the incumbent technology for most switch applications. Unfortunately, these PIN diode based switches are prohibitively large for most highly integrated modules, especially those requiring six throw switches (ie quad band architectures). Recent improvements in depletion mode pHEMT fabrication and design have allowed for outstanding linearity and low insertion loss performance. Die area for a typical single-pole six-throw pHEMT switch is on the order of 1mm^2, significantly increasing the GaAs content in future handsets. Also, this added functionality will reduce the amount of work required of the handset designers, allowing for a quicker time to market.

Figure 5 shows the estimated GaAs die area per handset looking back five years and projecting forward through

2007. The forecasted die area demand is based on a model that blends together different handset modulation standards and their associated volumes, multi-band and multi-mode functionality, as well as component integration changes over time. This model predicts that the GaAs area per handset will increase by more than 40% over the next three years. This increase is slightly higher than the 30% cumulative area increase that has been seen during the previous three years. Key assumptions for this model have been summarized throughout this paper. Also, this data is normalized to a per handset calculation and therefore does not account for the overall market share of GaAs based PAs.

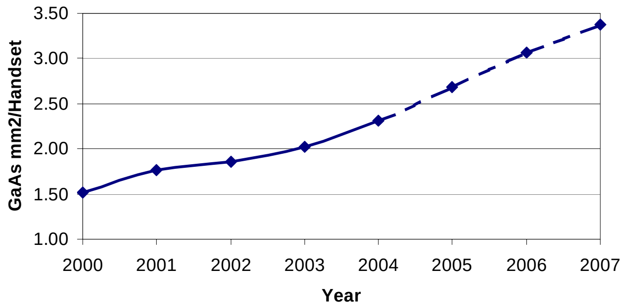


Figure 5 GaAs die area per handset over a eight year period

CONCLUSIONS

GaAs semiconductors and specifically HBTs were the big market share winners for PA solutions during the last decade. Costs dropped an order of magnitude as volumes increased dramatically. Customers continue to demand for more integrated components. They want “plug-n-play” solutions for their handset radios. These solutions must provide lower total cost, smaller total solution size, and significantly fewer components. In summary, the semiconductor technology that can provide “cost effective PA integration” will proliferate throughout the remainder of the decade.

Additionally, GaAs pHEMT is positioned very well to capture significant antenna switch volume during the next few years. This is an enabling technology for developing small transmit modules in the future. Longer term, this integrated transmit section should serve as the cornerstone for a cost effective, multi-mode, multi-band single placement radio.

REFERENCES

[1] D. Streit, et al., *High-Reliability GaAs-AlGaAs HBT’s by MBE with Be Base Doping and InGaAs Emitter Contacts*, IEEE Electron Device Letters, vol 12, no. 9, Sept 1991.

ACRONYMS

HBT: Heterojunction Bipolar Transistor
MESFET: Metal Semiconductor Field Effect Transistor
LDMOS: Lateral Diffused Metal Oxide Semiconductor
pHEMT: Pseudomorphic High Electron Mobility Transistor
GSM: Global System for Mobile communication
GPRS: General Packet Radio Service
EDGE: Enhance Data GSM Environment
CDMA: Code Division Multiple Access
WCDMA: Wide-band Code Division Multiple Access
TDMA: Time Division Multiple Access
2G: Second generation wireless communication standards
3G: Third generation wireless communication standards
SMD: Surface Mount Device