GaAs ICs for 3 Volt Electronics

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Abstract

As batteries go, so goes portable electronics. In the near future, small and light 3 volt batteries will become available. It necessitates future power supplies for notebook PCS, cellular and DCS/PCS handsets and HPCs (handheld PCS) to move from 5 to 6 volts to 3 volts. Consequently, both RF and baseband ICs will need to operate satisfactorily down to 2.5 volts to account for the aging of the battery.

The high electronic mobility and low knee voltages of GaAs transistors are ideal for low supply voltage operations. Integrated power amplifiers for cellular handsets have good performances down to 1.5 volts. DC to DC converters with better than 95% conversion efficiencies are also available.

We will address key technical and application issues in this talk.

Introduction

Constant complaints about cellular phones are the batteries. Not only are they big and heavy but compared to paging, they also have a short operating life. Consequently, handset manufacturers have been designing away from the bulky 6 volt, five cell nickel metal hydride batteries and have been designing in 3 volt, single cell lithium ion, lithium metal or lithium polymer batteries. Lithium batteries are smaller, lighter and have higher charge densities than nickel metal hydride batteries as shown in Table I.

Table I. Battery Properties

Characteristics	NiMH	Li-Ion	Li-Metal	Li-Polymer
Unit cell voltage	1.25	3.6	3	2.2
Energy density. Wh/kg	55	100	140	400
Volumetric efficiency, Wh/l	180	225	300	500
Cost, $/WH	1.5 to 3.0	2.5 to 3.5	1.4 - 3.0	?
Memory effect?	No	No	No	No
Self-discharge rate, %/month	20 to 25	8	1 to 2	?
Environmental concerns	No	No	No	No

The power consumption of digital integrated circuits (IC), such as logics, memories and digital signal processors (DSP), is directly proportional to the square of supply voltage. Therefore, moving supply voltages from 6 to

3 volt reduces the power consumption of digital electronics by three quarters. Lower power consumption not only extends the battery life but also lowers the heat dissipation. Consequently, cutting the handset manufacturing cost and enhancing its reliability.

However, low supply voltages pose special challenges to radio frequency (RF) components, especially, power amplifiers (PA) for the transmitters. Traditionally, RF power amplifiers are made with silicon bipolar or MOSFET technologies using 6, 12, or 24 volt power supplies. Bipolar and MOSFET transistors have high breakdown voltages and are ideally suited for high power and high voltage operations. However, their performance levels drop off substantially as supply voltages are reduced from 6 volt to 3 volt. This leaves a window of opportunity for GaAs IC PAs.

- **GaAs IC Technology for Handset PA**

There are three GaAs transistors for handset PA applications: MESFET, PHEMT and HBT.

The device cross section drawing is shown in Fig. 1. Basic device parameters are shown in Table II.

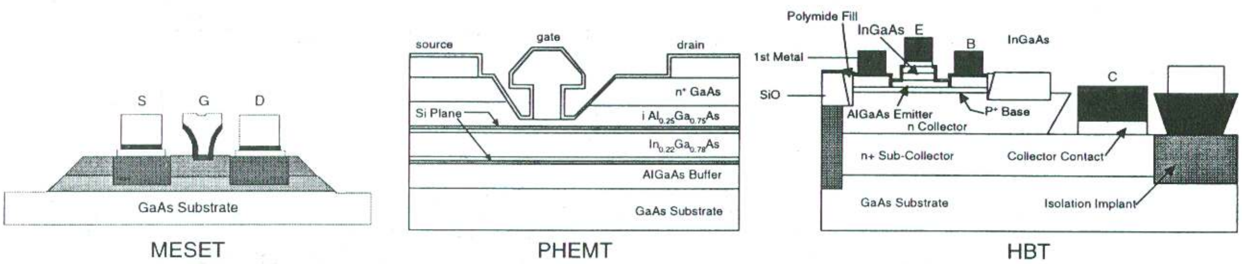


Fig. 1 Device Cross Section

Table II. Basic Device Parameters

	GaAs MESFET	GaAs PHEMT	AlGaAs/GaAs HBT
Size (μm)	0.5x5	0.5x5	2x5
BV_{ceo}/BV_{ds}	18	15	15
Ft (GHz)	30	45	50
Gain (dB) @ 2 GHz @10 GHz	 20 13	 22 15	 19 13
Nf_{min} (dB) @ 2 GHz @10 GHz	 0.3 0.9	 0.3 0.6	 1.5 High
$IP3/P_{1dB}$ (dB)	12	12	16
P.A.E. @ 3V	70%	80%	40%
1/F Corner (kHz)	2,000	20,000	1,000

Pros and cons of each technology for 3 volt PA applications are shown in Tables III, IV and V.

Table III. MESFET

Pros	Cons
Low wafer cost	Dual supply
High Eff at lower voltages	Small feature sizes <0.5
High g_m*R_d	
High F_t capability >20 GHz	
Good IMD performance	
Low cycle time	

Table IV. PHEMT

Pros	Cons
High Eff at lower voltages	High wafer cost
High g_m*R_d	Dual supply
High F_t capability >40 GHz	Lower reliability
Good IMD performance	Longer cycle time
Low noise	Small feature sizes <0.5 µm

Table V. GaAs HBT

Pros	Cons
Signal supply	High wafer cost
High g_m*R_x	Longer cycle time
High F_t capability >20 GHz	Many mask steps
Large feature sizes >1 µm	Reliability questions
Good IMD performance	

- **Optimal MESFET for 3 Volt PA**

In the immediate future, ion implanted GaAs MESFET PA is the most cost effective solution for 3V handset applications.

Figure 2 is a simplified MESFET device cross section. For optimal power amplifier performance, the gate Length Lg needs to be at least three times the channel thickness W. As the gate length Lg is reduced to 0.5 µm or less W needs to be reduced accordingly. In Fig. 3, an implantation profile for 6 volt PA is shown and in Fig. 4, a shallow profile for optimal 3 volt PA is shown.

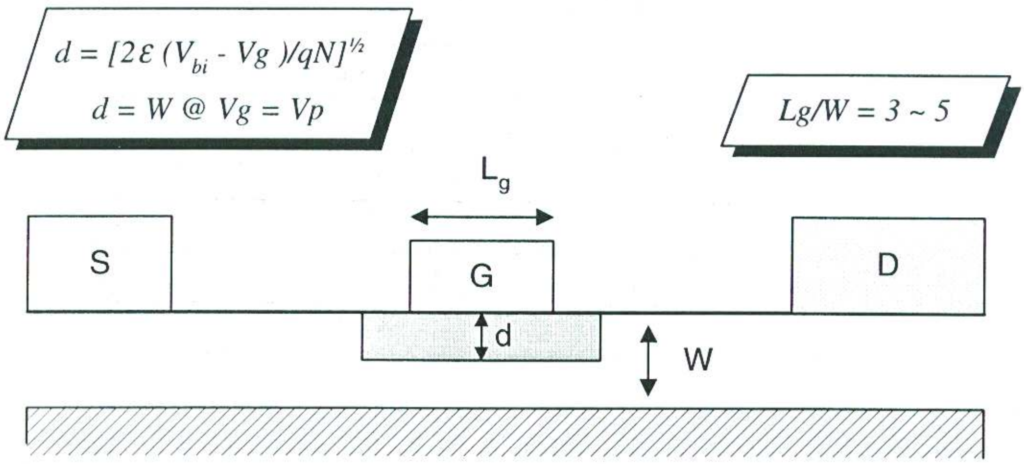


Fig. 2 MESFET Device Cross Section

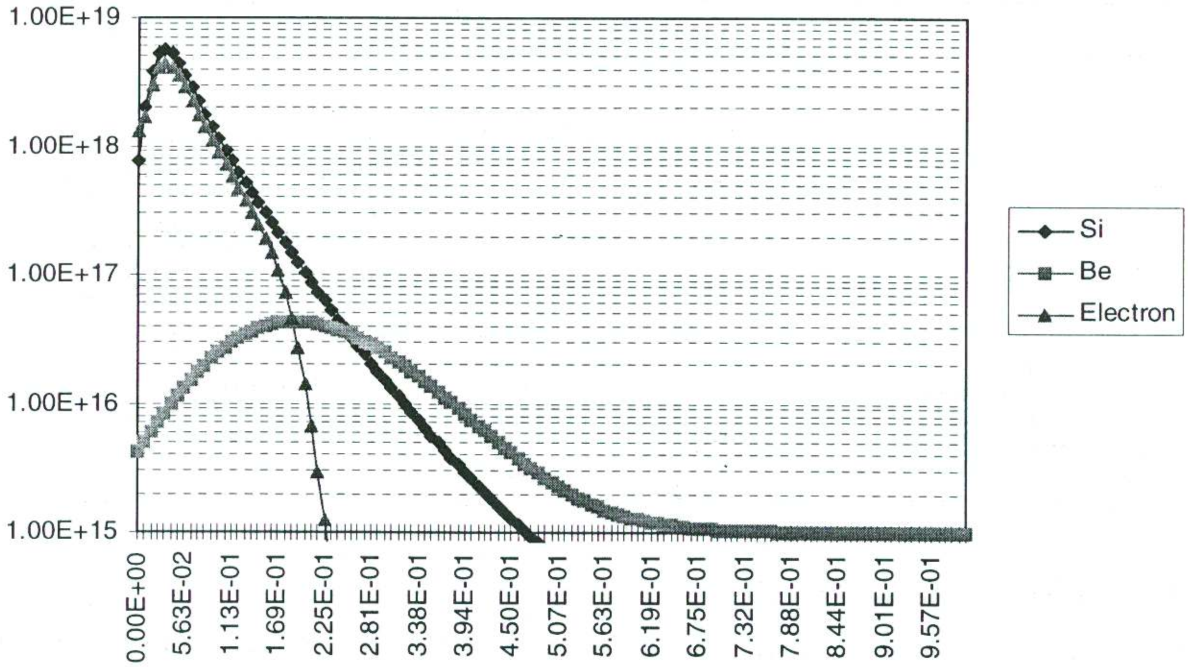


Fig. 3 Regular Implant Profile

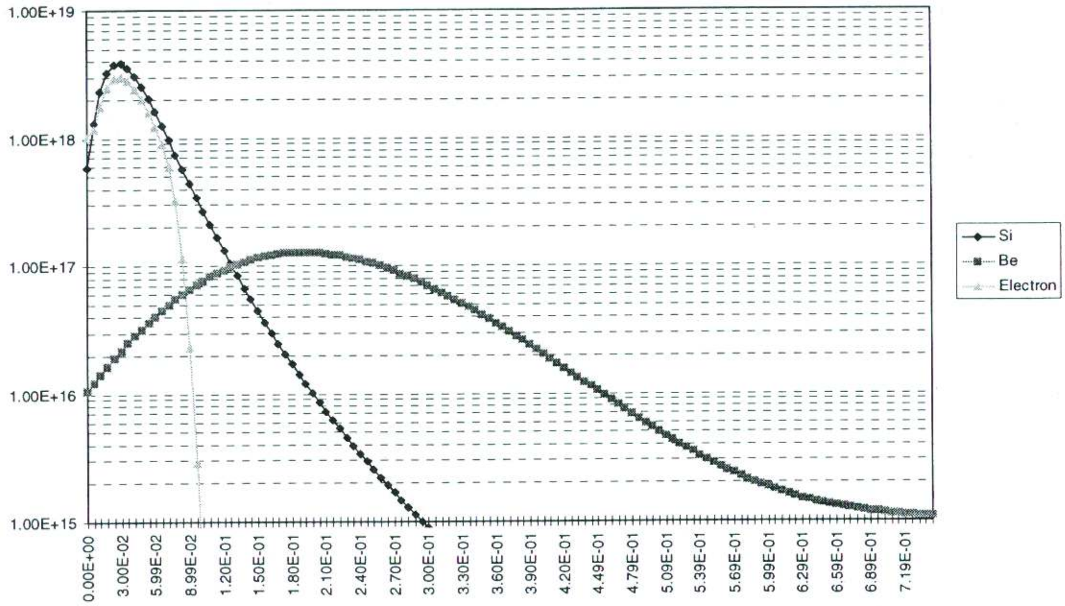


Fig. 4 Shallow Profile

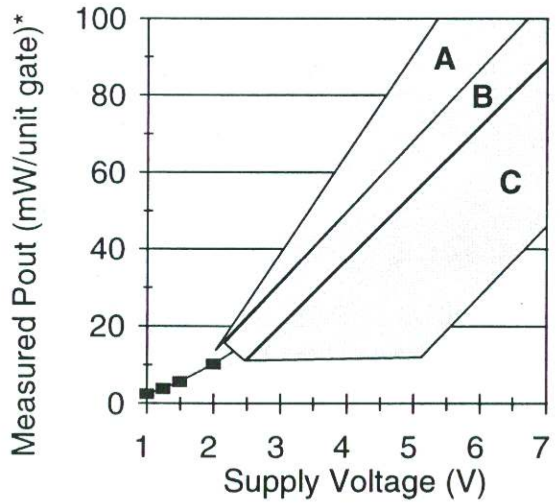
In Table VI, the target values for 3 volt PA MESFET is shown.

Table VI. Target Values for 3V Power MESFET

Parameter	Condition	Target Value	Unit
Idmax	Vds=2.0V; Vgs=0.6V	300	mA/mm
Idss	Vds=2.0V; Vgs=0V	150 ~ 180	mA/mm
Vp	Vds=2.0V @ 3%Idss	-0.9 ± 0.1	V
Vk	Vgs=0.6V	1.0	V
BVgdo	Ig=1mA/mm	10 ~ 12	V
RF Gm	Vds=3V; 50%Idss	≥200	mS/mm
fT	Vds=3V; 50%Idss	≥20	GHz
P1dB	2GHz	>150 (norm. 200)	mW/mm

- **Low Voltage MESFET PA**

GaAs MESFET PAs available today typically contain two or three stages of amplification along with the appropriate input and interstage matching circuitry. The output matching network for the amplifier is performed with the use of a simple L-C circuit which utilizes higher off chip quality factor components for maximized performance. Newer generation PAs also include an active bias circuit and a DC-to-DC converter circuit which generates the negative voltage which is required by depletion mode devices to remain off. Fig. 5 shows the output power capability of some of commercially available PA designs as normalized to an arbitrary unit of gate width as a function of supply voltages.



A: Pulsed GMSK   B: CW Analog   C: Linear TDMA/CDMA

* Tuned for Max Power at each voltage

Fig. 5 Output Power Capability

The three regions which are shown generally describe the operating levels utilized by pulsed (Region A), analog (Region B) and linear (Region C) applications. Linear amplification which is required for TDMA pi/4 QPSK and CDMA modulation requires that the devices in the PA run at levels below saturation. With proper scaling and design, a personal digital cellular (PDC) part was developed which has adjacent channel power (ACP) levels of <-50 dBc at an output power of +31 dBm while operating at 3.5 volts with 35% efficiency.

A comparison between the 3.5 volt and 5.8 volt GSM (region A) design shows that the output device must be scaled approximately 2:1 to achieve the required +35 dBm of power which can increase costs but due to the fact that on chip power densities also will drop by this factor, the larger device geometries can be packed more densely for size reductions.

Some investigation was done to see how well standard processing can produce RF power at and below 3 volts at cellular frequencies. This prototype PA was designed and fabricated using conventional on chip geometries and processing. The die size was 2.1 mm^2 and was assembled in a plastic SSOP 28 package. 900 MHz RF testing at 3 volts achieved +35 dBm out for +7 dBm in with an overall efficiency of >44%. Additionally, direct RF conversion at the 1 watt level from supply voltages as low as 2 volts can be achieved. Power added efficiencies of 40% were also demonstrated at this power level. Fig. 6 shows compressed power capabilities of the die below 2.5 volts.

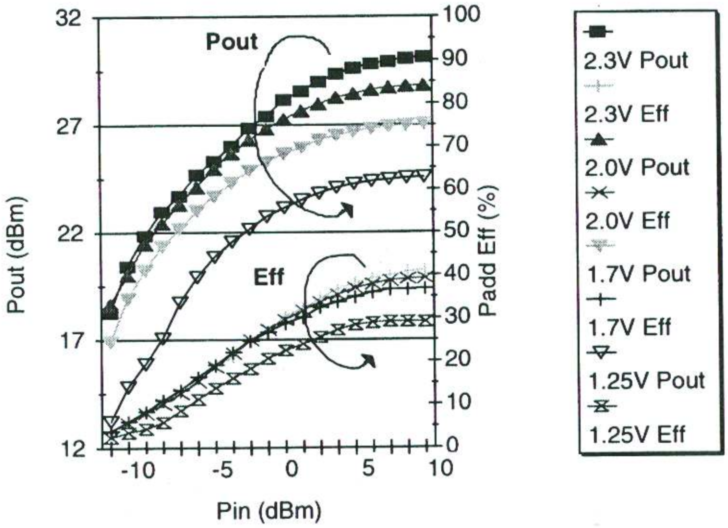


Fig. 6 Compressed Power Capabilities

- **Power Distribution Circuitry**

A list of power supply circuit topologies allowing digital circuit to operate at lower or equal voltages than that of the analog section is shown in Table VII, along with possible positive and negative attributes.

Table VII. Power Distribution Circuit Summary

Circuit Topology	Advantages	Disadvantages
LDO (Low Drop Out) regulator	Simple	Inefficient
Switched buck regulators	Efficient	EMF & Noise, large passives, multiple components required
Charging internal batteries from non-rechargeable source	Used to fit existing standards	Complex charge circuit, limited transmit time, internal battery cost
Voltage doublers, triflers, etc.	Efficient	EMF & Noise, large storage capacitor, multiple components required, limited transmit time
Digital and RF operate at the same voltage	Efficient, simple	No regulation

Due to various design targets of cost, size and performance, no universal topology can be applied to all wireless applications. Compatible voltage operation of the digital and analog circuits is the simplest solution and also will require the least additional components.

- **<u>GaAs MESFET DC-DC Converters</u>**

Figure 7 shows the basic block diagram of a charge pump type DC-DC converter.

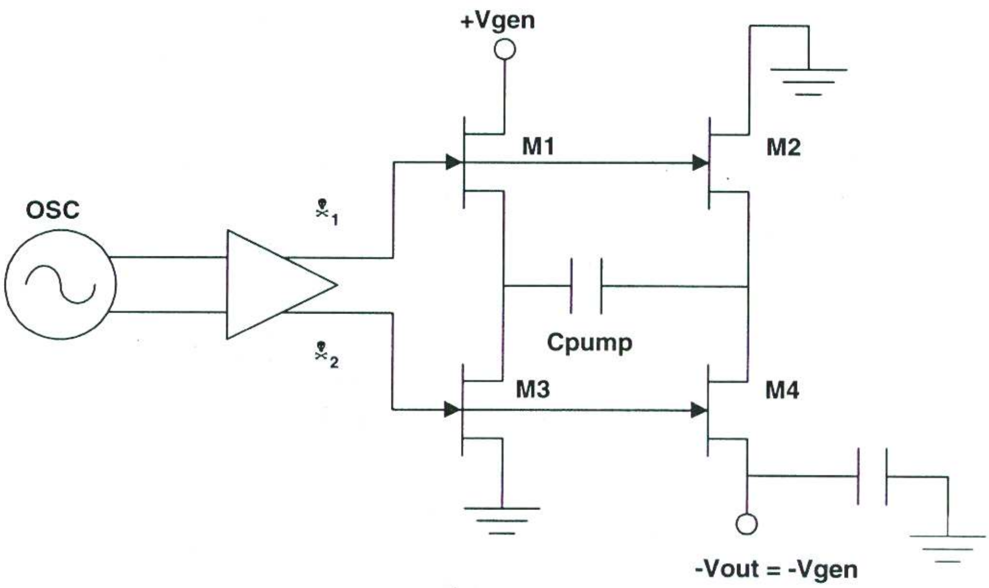


Fig. 7 Basic Block Diagram For a DC-DC Converter

The GaAs MESFET converter offers improved low voltage operation in a smaller package than its silicon counterparts.

A simple model for DC-DC converters is a battery of -Vdd volts in series with a resistor. As the load current is increased, the negative voltage goes more positive as voltage is dropped across this output resistor. The low threshold voltage of GaAs MESFETs (typically -0.5V) allows the MESFET converter to maintain its output impedance even at low supply voltages. Figure 8 shows how the output voltage of the MESFET converter changes with the load current. A typical silicon part is shown for comparison. Figure 9 illustrates the nearly constant output impedance of the MESFET converter.

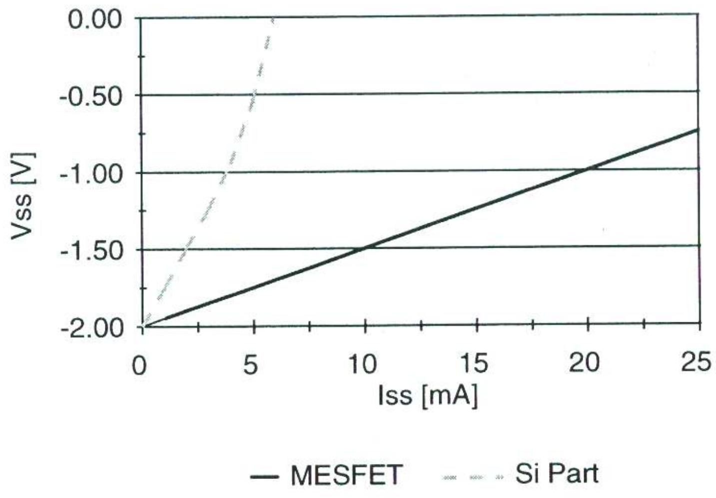


Fig. 8 Output Voltage As A Function Of Sourced Current

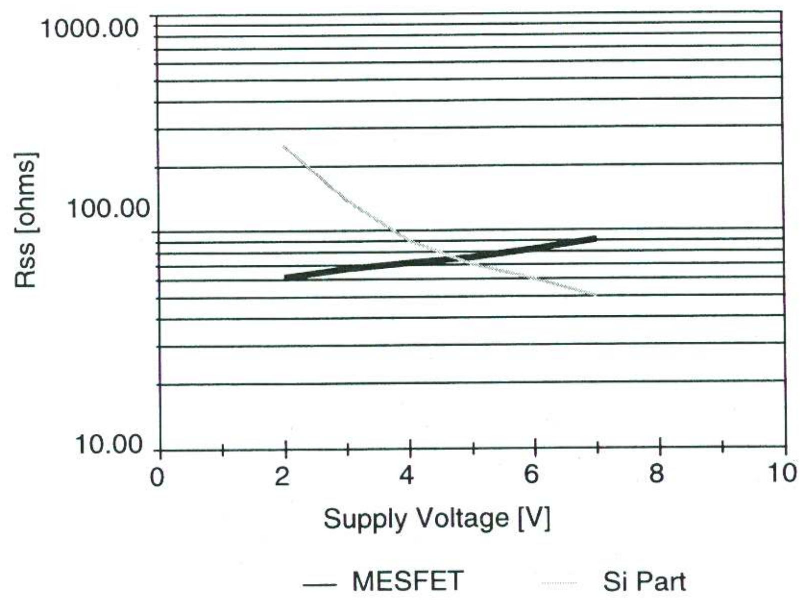


Fig. 9 Output Impedance (3mA load) As A Function of Supply Voltage

Summary

GaAs ICs are ideally suited for 3 volt cellular and PCS handset applications. In particular, encouraging performance of 3 volt power amplifiers and DC-DC converters have been demonstrated.