RF Power Amplifiers for Cellphones

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Abstract

A wide variety of semiconductor devices are used in wireless power amplifiers. The RF performance and other attributes of cellphone RF power amplifiers using Si and GaAs based technologies will be reviewed and compared.

INTRODUCTION

A key component in any wireless communication system is the RF power amplifier that is enabled by a wide variety of semiconductor technologies. These amplifiers must meet strict performance specifications, output power and linearity, so that the wireless systems comply with ITU (International Telecommunication Union) regulations. In addition, system manufacturers have their own requirements: power-added efficiency (PAE), supply voltage, ruggedness, physical size, reliability, and cost. These amplifiers are used in cellphones that have very different specifications depending on the modulation format of the wireless system. The RF performance and other important attributes of these amplifiers will be compared for GSM, DCS, CDMA and WCDMA cellular applications

SEMICONDUCTOR TECHNOLOGIES

A wide variety of semiconductor technologies have been used to build cellphone RF power amplifiers: Si BJT, SiGe HBT, Si LDMOS FET, GaAs MESFET, GaAs HFET, and GaAs HBT. The semiconductor technology and, more specifically, the large, output power device in the final stage of the PA determine, in large part, the performance of the RF power amplifier. In a recent paper [1] the author reviewed and compared the performance of these large, output power devices for GSM, DCS, CDMA, and WCDMA applications. For each application several different semiconductor technologies were found to provide adequate performance. No single technology had superior performance for all applications. Each technology had strengths and weaknesses that could be exploited by the RF amplifier designer. The higher power density of GaAs HBT's leads to smaller die size. GaAs FET's have higher power gain and PAE. Si LDMOS FET's are the lowest cost even though they have the lowest power density and therefore, the largest die size. In general, FET's are much more rugged than HBT's that is the ability to survive large load mismatches, up to 15:1, while delivering the rated output power. Compared to Si LDMOS, GaAs FET's and GaAs HBT's, SiGe HBT's are relatively new to this application space. The remainder of this paper will compare the performance of RF power amplifiers fabricated with these semiconductor technologies for GSM, DCS, CDMA, and WCDMA cellphones.

GSM 900 MHz

For the constant envelope applications, GSM and DCS, the important amplifier figures of merit are RF power and power added efficiency (PAE) at the supply voltage. The amplifier data in Fig. 1 allows a comparison of the PAE of GaAs based InGaP HBT's [2-4] and HFET's [5-7] and Si based BJT's [8], SiGe HBT's [9,10], and LDMOS [11] technologies in the 900 MHz GSM application. In comparing amplifier performance knowledge of the supply voltage is very important because output power and PAE should both increase as the supply voltage is increased. Therefore, technology comparisons would be easier if all amplifiers were tested at the same supply voltage. When comparing literature data this is not possible and therefore, the supply voltage for each amplifier is included in Fig. 1. The GaAs FET amplifiers achieve their high PAE's with the

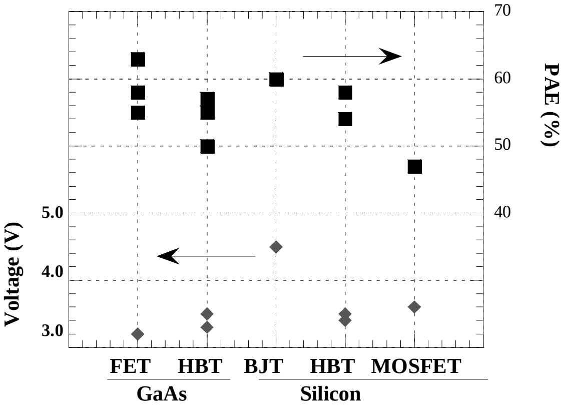

Figure 1. GSM power amplifiers using GaAs (InGaP HBT and HFET) and Si (BJT, SiGe HBT, and LDMOS) technologies.

lowest supply voltage 3.2V. Since the other amplifiers are operated at higher supply voltages, especially the Si BJT 4.5V, their PAE's should be lowered somewhat to take into account the supply voltage effect. Having done this, the GaAs FET's clearly have the highest PAE followed by the InGaP HBT's SiGe HBT's, Si LDMOS, and Si BJT amplifiers. The Si BJT amplifier [8] uses the push-pull design approach and achieves high PAE 59%, but requires a 4.5 V supply voltage. All of these amplifiers have an output power equal to or greater than 35.5 dBm except the SiGe HBT that has 35 dBm output power.

Several other factors need to be considered when comparing the reported performance of RF amplifiers fabricated with different device technologies. The first of these is the issue of amplifier ruggedness that is its ability to survive load mismatch while delivering rated output power. FET's offer adequate ruggedness for cellphone PA's without the need for protection circuitry that is often used with HBT's. Using ruggedness protection circuitry, an AlGaAs HBT PA survived 10:1 VSWR at Vcc = 3.2V [12] and a SiGe HBT PA survived 10:1 VSWR at Vcc = 5V [9]. BJT and HBT PA results that do not report ruggedness performance should be viewed with some skepticism because the PA may have been designed to maximize output power and PAE with no thought to the equally important ruggedness requirement. Other factors that can affect PA performance that cannot be taken into account for this comparison are the skill of the amplifier designer and the accuracy of the RF characterization.

DCS 1800 MHz

DCS is also a constant envelope application and therefore, important amplifier figures of merit are RF power and power added efficiency (PAE) at the supply voltage. The amplifier data in Fig. 2 allows a comparison of the PAE of GaAs based InGaP HBT's [2,13] and HFET's [5-7], and Si based BJT's [14] and SiGe HBT's [9,10] technologies in the 1800 MHz DCS application. In comparing these amplifiers the operating voltage must be taken into account again. Unfortunately three of the bipolar references [10, 13, 14] do not report on amplifier ruggedness that raises several questions that cannot be answered definitively. Are these amplifiers sufficiently rugged for cellphone applications? If they are not sufficiently rugged, how much will their performance deteriorate in the process of improving their ruggedness? Therefore the highest GaAs HBT, Si BJT, and SiGe HBT PAE's shown in Fig. 2 should be viewed with some skepticism. Putting these questions aside, the GaAs HBT, GaAs HFET, and Si BJT have the highest PAE around 60% (Fig. 2). The PAE of the SiGe HBT amplifiers has dropped substantially at 1800 MHz when compared to that at 900 MHz. All of these amplifiers have an output power equal to or greater than 33 dBm except the SiGe HBT that has 32 dBm output power.

CDMA 1900 MHz

For linear applications, CDMA and WCDMA, PAE and output power are also very important, but only so long as linearity specifications ACP (Adjacent Channel Power) are met at the required output power levels. The CDMA system level specification is –42 dBc and power amplifiers need to best this specification by about 2 dB. The amplifier data in Fig. 3 allows a comparison of the PAE and ACPR of GaAs based HFET's [15] and InGaP HBT's [16] and Si based BJT's [16] and SiGe HBT's [9,16,17] technologies. All of these amplifiers handily meet the ACPR specification, but the GaAs HBT and one of the SiGe HBT's demonstrate superior PAE. All of these amplifiers have at least 28 dBm output power from 3.0-3.4 V supply. The data points connected by the solid lines are all from the same reference [16] and therefore, allow a more valid comparison of these technologies. It should also be noted that the PAE for CDMA applications is lower than that for the saturated applications GSM and DCS because the amplifier output power must be backed off to meet the ACP requirement.

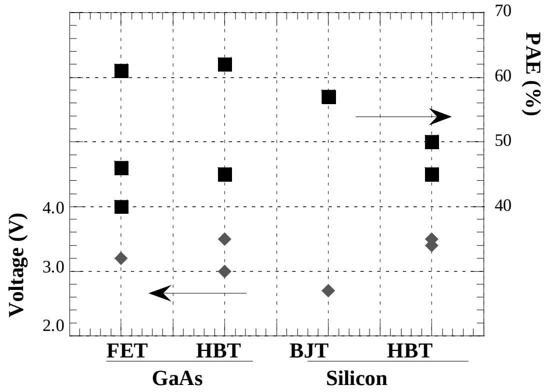

Figure 2. DCS power amplifiers using GaAs (InGaP HBT and HFET) and Si (BJT and SiGe HBT) technologies.

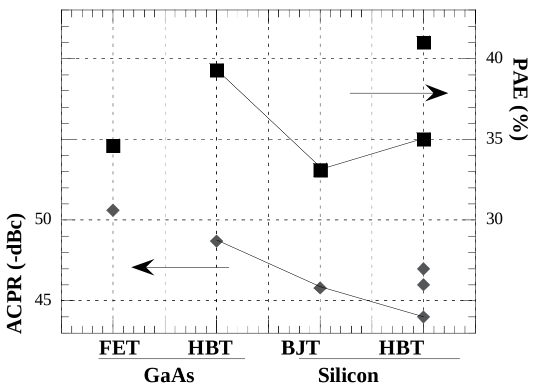

Figure 3. 1900 MHz CDMA power amplifiers using GaAs (HFET and InGaP HBT) and Si (BJT and HBT) technologies.

WCDMA 1900 MHz

For WCDMA, another linear application, PAE and output power are also very important, but only so long as linearity specifications ACP (Adjacent Channel Power) are met at the required output power levels. The WCDMA system level specification is – 33 dBc. Again allowing about 2 dB margin between the amplifier ACP and the WCDMA ACP specification, all of these amplifiers (Fig. 4), GaAs FET [18,19] and InGaP HBT [20-25] and SiGe HBT [9] meet the ACP specification. The GaAs based FET and HBT amplifiers have higher PAE than the SiGe HBT. The PAE of the WCDMA amplifiers is also lower than that of the saturated applications because of the need to meet the ACP requirement. These amplifiers deliver 26-28 dBm output power using 3.4V – 3.6V supply voltages.

AMPLIFIER DIE SIZE

Aside from meeting RF performance specifications, another very important amplifier consideration is die size because this strongly impacts die cost. The following references provided die size information (Fig. 5) for the various semiconductor technologies for GSM, DCS, CDMA, and WCDMA applications [2,3,5,6,8,9,13-15,22,25-27]. The device technology and the required output power determine the size of the final stage power device that is the largest in the amplifier. In most cases this device consumes over half of the die area. GaAs HBT's have the highest power density and therefore, it is not surprising that the smallest amplifier die utilize this device technology. GaAs FET's have lower RF power density and therefore, on the average, amplifiers using GaAs FET's have almost twice the die area. SiGe HBT's amplifiers have die areas similar to GaAs FET's and Si BJT's have the largest die areas. The large range in die area for each technology is a result of other factors: level of integration, bond pad size, scribe street width, and RF designer skill.

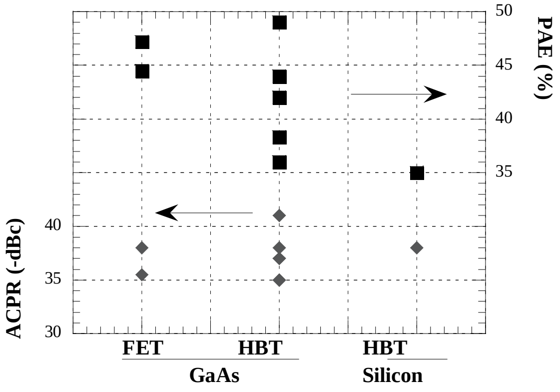

Figure 4. 1900 MHz WCDMA power amplifiers using GaAs (HFET and InGaP HBT) and Si HBT's technologies.

CONCLUSIONS

After reviewing the performance of RF amplifiers utilizing a variety of semiconductor technologies, it is clear that no one technology dominates the application space. In fact for each application several different technologies can meet the RF specifications. Each technology has positive and negative features that may or may not be important for a particular application. LDMOS amplifiers seem limited to 900 MHz applications, but are the lowest cost. GaAs FET amplifiers appear to have higher PAE and are more rugged. GaAs HBT amplifiers have the smallest die size. The PAE performance of SiGe HBT's is somewhat inferior to GaAs based FET's and HBT's.

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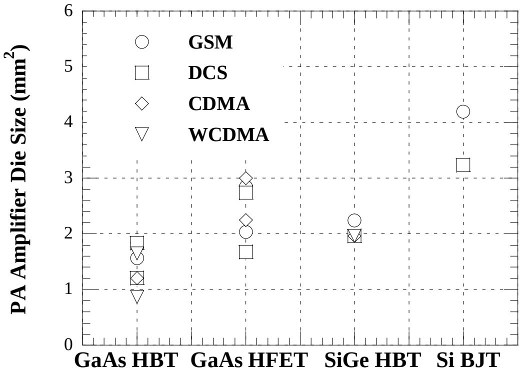

Figure 5. Power amplifier die area for GaAs (HFET and HBT) and Si (SiGe HBT and BJT) technologies.

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