3G/4G Requirements for Wireless Systems and the Role of GaAs and GaN

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Abstract

The requirements of the wireless industry—end user equipment (terminals) and system infrastructure—are arguably placing greater demands on RF and microwave designers than ever before. From handsets to base stations (macro to femto), as well as backhaul, the trend is for higher levels of integration (fewer discrete devices), greater device and amplifier linearity and efficiency, combined with overall improvements in other leading performance parameters. All are driven by the leading edge of third generation and emerging fourth generation wireless networks, including HSPA+, LTE and WiMAX. These networks are relied upon by an ever increasing proliferation of smartphones and other broadband mobile devices that achieve internet connectivity as a key function. This paper describes some of the central trends in RF and microwave design that are enabling networks and terminal equipment, as well as what the future holds, demonstrating that the evolution of gallium arsenide (GaAs) and gallium nitride (GaN) semiconductor technology is critical in meeting the RF requirements of 3G/4G devices and networks.

INTRODUCTION

The availability of high-speed data services is transforming the complexion of traffic on wireless networks from mostly voice to mostly data, the latter increasing at an astonishing rate (Figure 1). This trend will continue to spiral upwards as more and more people upgrade from feature phones to smartphones, and the majority of smartphones (and other wireless-enabled devices) incorporate the latest technology, which will ultimately be LTE-Advanced. As 4G establishes itself, data rates will rival those currently available only from wired residential services such as cable and fiber-to-the-premises (FTTP).

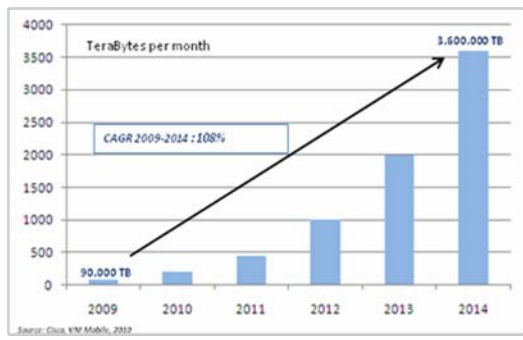

Figure 1: Global Mobile Data Traffic Forecast

RF and microwave technology will play a key role in allowing networks and user equipment to embrace these advancements and the task is not trivial. Smartphones, for example, must today transmit and receive in multiple portions of the 900 and 2000 MHz bands, the new 700 MHz band to be occupied by LTE, 2450 MHz for WiFi and Bluetooth, receive at 1575 and 1227 MHz for GPS, and soon transmit and receive at 13.56 MHz for Near Field Communications (NFC) transaction processing. These factors, combined with the numerous modulation schemes utilized by these services along with the need to develop electrically-short yet effective antennas in conjunction with Multiple Input Multiple Output (MIMO) spatial diversity while dealing with inevitable internal interference issues, make for a challenge of mammoth proportions. This increasing demand for spectrum generates a severe coexistence challenge (e.g. for WiFi and 4G [WiMAX] within the same device or in close proximity to one another.) Advanced filter technology is the only solution to enable the usage of these spectra with the steep, temperature insensitive filter skirts. Enabling technologies are Bulk Acoustic Wave (BAW) and Temperature Compensated Surface Acoustic Wave (TC-SAW) processes (ref1). Furthermore, advanced compound semiconductor technologies are essential in Mobile Terminals as well as Base Station sections with their material-specific benefits compared to Si technologies.

Mobile Terminals

Currently, typical mobile terminals for smartphones are equipped with quad band GSM/EDGE and one to four bands of WCDMA channels. The standard today is quad band GSM/EDGE power amplifier (PA) module or transmit module (PA and antenna switch). In the WCDMA section, solutions are used with a discrete PA lineup and filters as well as PA-duplexer modules with and without transmit filter. Starting from the high end Smartphone markets, there will an additional requirement for more 3G/4G channels and higher data rate following the trend as shown in Figure 1. In parallel, the available printed circuit board (PCB) space that industrial phone design will allow is limited or will even decrease as additional hardware content for new features is added. Besides this space aspect, overall cost, linearity and efficiency are well known drivers of RF front-end evolution. In a first step toward higher phone board integration is a move to repackaging the existing PA into single modules; this has already occurred in the 3G landscape as it did in 2G (System in Package, SiP). Another challenge is to meet the need for more filtration in the WCDMA/LTE duplexer area (Tx pass band, Rx pass band). These filters cannot be 'shrunk', and tunable filters with the required performance will not be available in the near future. The next integration level will occur on the power amplifier side. High linearity broadband power amplifiers that cover multiple low / high bands in the 3G and 4G frequency channels will enter the market. This will be followed by an integration of 3G and 4G mode into a single broadband power amplifier device also covering GSM/EDGE at the same time (System on Chip, SiC). The most challenging part of this integration evolution will be on the design side because a compromise on efficiency at a system defined linearity level will not be specifically accepted. Further efficiency improvements will likely force advanced technologies like envelope tracking and pre-distortion into designs for mobile terminals.

Base Station

The increased usage of wireless communication is enabled by the extension of wireless infrastructure and base stations throughout the world. The demand for green base stations becomes very evident from Figure 2, which shows the CO_2 emissions that are directly related to the mobile industry. Only 4% is directly related to the charging of the mobile terminals and keep them running, and 13% is due to the manufacture and deployment of the network equipment, but not to run it. The largest part with 71% of the emissions is generated from powering the mobile network itself. This causes a huge pressure to enhance the base stations power amplifier efficiency and

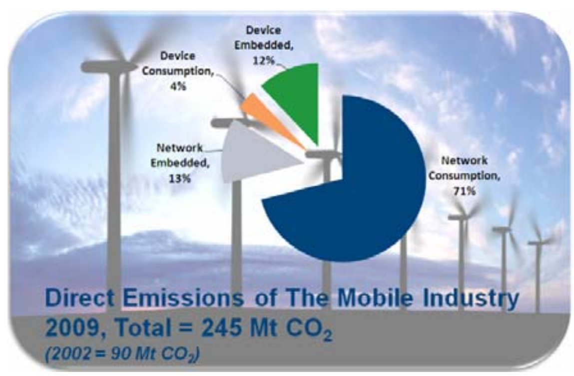

Figure 2: Mobile Industry CO_2 emissions; Source: GSMA Green Manifesto, Nov 2009

only a few points worth of improvement here have a large impact on the energy consumed and emissions generated. Efficiency enhancement techniques like pre-distortion, dual- and triple-Doherty architectures are standard today.

Applying envelope tracking and the ease of implementation of the complex systems are well recognized differentiators. Smaller footprints and the reduced cooling requirements and air conditioning are selection criteria as well. A typical lineup efficiency advantage of 6-7% of a TriQuint TriPower base station RFIC can be seen when used in a Doherty configuration; this transfers into a 15% energy saving and a 25% reduction in heat dissipation compared to an LDMOS solution.

III-V components and filters

It is well known in the industry that the material properties of compound semiconductors enable more advanced devices at the same technology node compared to Si devices. A comparison for power devices highlighting this advantage was published by Nellis and Zampardi (ref 2).
Si technologies have improved over time and closed part of the difference, specifically for lower power devices, by reducing the feature size far down into the sub micrometer range at the cost of also reducing the maximum application voltage and breakdown voltage of the device, and thus limiting the potential application fields. In order to overcome the parasitic substrate effects some applications are moving away from bulk Si to higher resistive material like Silicon on Sapphire (SOS) or Silicon on Insulator (SOI).

The challenging demand for highest efficiency and high linearity at the same time and the extension of frequency spectra to higher frequencies insures that compound semiconductor technology will dominate this field for mobile terminals and will begin to invade into the base station market with HV-HBT now and GaN thereafter. The TriQuint technology portfolio offers the broadest technology choices for the mobile industry covering pHEMT, HBT, BiHEMT, HV-HBT and GaN processes together with the SAW, TC-SAW and BAW acoustic filter processes, all under one roof.

The GaAs pHEMT technologies cover a broad process spectrum from 0.5um, 0.25um down to 0.15um and 0.13um gate length and offer very good coverage of cellular frequency applications; products include ultralow insertion loss and the highest linearity switches for antenna or diversity applications as well as low noise amplifiers (LNA), WiFi PAs, and digital control functions. All the referenced pHEMT processes are oriented toward high volume manufacturing and are based on optical gate definition; no e-beam writing is required. The high volume-proven HBT processes are based on highly-reliable InGaP technology and are mostly used for PAs. TriQuint has developed an advanced flip-chip process using CuFlip™ copper pillars. These can be placed directly on top of the heat sources in the HBT device and therefore generate a low thermal impedance die attach. CuFlip™ is also a very space-efficient technique since all the wire bond area on the PCB are no longer required.

The HV-HBT has been extensively optimized for higher gain and improved robustness for operating voltages of 32V with a base collector breakdown voltage of 85V. In this current HV-HBT generation, power transistors rated for 120W and 220W of continuous (CW) power in the 2.1GHz band deliver 16-17dB gain at P-1dB and a saturated efficiency in excess of 70%. Doherty amplifiers at 120W and 220W developed using TriQuint HV-HBT technology have demonstrated close to 14dB of gain and efficiencies larger than 55% at 6dB operating backed-off from 1dB compression. These amplifiers also demonstrate the advantage of easy linearization to -55dBc using DPD.

The TriQuint high power GaN baseline 0.25um HEMT devices are manufactured on 100mm AlGaN/GaN on SiC wafer material. This material has a huge potential to penetrate into the base station market because its reliability has been demonstrated and its higher frequency performance exceeds LDMOS as well as HV-HBT. Cost effectiveness of GaN-based devices continues to improve relative to other compound semiconductor technologies.

Filtering is an enabling part of the 3G/4G full duplex systems. Low cost acoustic filter technologies (SAW and BAW) based on piezoelectric materials play a key role as they guarantee the spectral integrity. Most SAW filters nowadays are manufactured on monocrystal piezoelectric materials such as $LiTaO_3$ and $LiNbO_3$. SAW devices require two to four mask layers depending on interconnect and die bonding techniques. The core resonator structure is based on interdigitated transducers (IDT). The frequency of a resonator is directly defined by the pitch of the metal lines, thus lithography and pattering of the IDT becomes a challenge for frequencies above 2GHz. The pitch shrinks to below 0.3um.

BAW resonators rely on the piezoelectric properties of mostly sputtered polycrystalline AlN layers on a high resistivity Si wafer. The manufacturing of standard BAW filter requires about 9 to 13 mask layers. While the mask count is higher compared to SAW, the lithography is not challenged. The frequency setting is defined by the layer thicknesses and the resonator area. Very tight thickness control and trimming procedures are mandatory for high yield fabrication across a wafer. BAW has the advantage over SAW filters at higher frequencies since the BAW resonator area shrinks with $1/f^2$.

For a PCS duplexer (band 2) the transition gap between Tx and Rx passband is 20MHz at about 1920MHz. This demands a very low temperature coefficient of frequency (TCF) in order to maintain isolation between the Tx and Rx. BAW filters, with their solidly-mounted resonators on the underlying Bragg reflector, offer very acceptable performance. For SAW, however, TriQuint has developed a temperature compensation process that dramatically improves the TCF performance. This process is referred to as the temperature compensated SAW process (TC-SAW).

Conclusion

The increasing demand for data via broadband mobile communication will further drive the compound semiconductor supplier to develop devices for mobile terminals and base stations that address improvements in cost, linearity, efficiency, size, and quality.

Filter solutions will become an increasingly important part of the frontend complexity and have to be incorporated appropriately while progressing along the integration path. TriQuint is very well positioned with all required technologies in-house for this challenging and rewarding task.

References:

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2) Nellis and Zampardi, IEEE Solid State Circuits, **39**, No 10, 1746-1754, 2004