# Some Recent Trends in RFIC/MMIC Technology

RFICs and MMICs are at the core of most high frequency, high speed electronic products, providing the necessary functionality. Amplifiers, mixers, modulators/demodulators, oscillators, synthesizers and switches are the main functions provided by these devices.

The choice of a particular device for a specific application has many variables—frequency of operation, gain, noise figure, power supply voltage and power consumption are key performance criteria. The level of integration (size) and cost are, of course, also key requirements for each application.

This report will review the status of most RFIC/MMIC technologies in use today, with particular note to the factors that would be considered advantages or disadvantages for each.

## GaAs, InGaP and Related Processes

The oldest gallium arsenide technology, MESFETs (metal semiconductor field effect transistor), remain in common use as switches, and in classic RF circuits at microwave frequencies. MESFETs offer reliability due to well-established processes and good noise performance, but are rarely the best choice for power amplification.

GaAs HBT (heterojunction bipolar transistor) technology is only slightly less well-established than MESFETs, having been promoted by TRW in the early 1990s and popularized by RF Micro Devices, the main commodity RFIC maker using this process. While still in use, today's HBT devices often are fabricated using InGaP, which offers improved performance in power amplification and high linearity RFICs and MMICs. For example, the highest performance general purpose gain block amplifiers now use InGaP HBT processes.

InGaAs pHEMT (pseudomorphic high electron mobility transistor) technology has rapidly risen to wide usage over the past few years. pHEMT devices generally offer lower noise performance than earlier technologies, without any corresponding reduction in dynamic range. High sensitivity applications such as top-of-the-line wireless handsets and GPS receivers have provided quantity markets for this technology.

Other processes in this family are in development, such as gallium nitride (GaN), which supports higher power applications, allowing greater integration in MMICs that previously required a separate power amplifier. Other wide band gap processes are being explored for higher microwave and millimeterwave MMIC applications.

Overall, GaAs and related processes have several advantages over other technologies, primarily higher frequency operation, relative ease of integrating passive components such as inductors, and either higher power or lower noise, depending on the particular process. The primary disadvantage is die cost per unit area, which limits its viability for high level integration.

## Silicon Germanium Becomes Commonplace

In RFICs, the widespread use of SiGe as a replacement for "classic" silicon bipolar is nearly universal. Even Linear Technology Corp., with its well-known capabilities in high performance silicon devices, is preparing to add a SiGe process to its fabrication capability.

Although it required several years of marketplace education and process refinement, the initial promise of SiGe—much higher $f_T$ than Si with minimal increase in cost or process complexity—has been realized. SiGe processes are central to the operations of major IC companies such as Freescale Semiconductor.

Early proponents of SiGe such as Atmel have combined their experience as foundry providers with their in-house design capabilities to offer high quality products for Bluetooth, GPS, WLAN and other current wireless applications.

With low processing cost and moderate power consumption, SiGe has found a clear niche (a sizeable one) where moderate to high levels of integration are needed in systems operating in the low GHz frequency range. Wireless handset up- and downconversion and WLAN products are among common applications.

SiGe processes can also provide devices operating into the millimeterwave range (up to 100 GHz), where high volume, low cost applications such as fiber optic communications and automotive sensors are being pursued.

## RF CMOS Gains Ground

RF CMOS continues to slowly gain momentum as a choice for RFICs. It's greatest potential is in the most highly integrated devices, so we see most publicity surrounding one-chip solutions for Bluetooth, ZigBee and other applications with requirements for very low cost, small size and the incorporation of significant digital circuitry, which is where CMOS excels.

As an example of RF CMOS processes, IBM's smallest-pitch (130-nm) foundry process includes as many as eight copper metal layers (or three thick layers), with an Al-Cu-Al sequence of the last metal layers. Users may also opt for a range of FET devices, from the standard set of NFET and PFET structures to an isolated triple-well NFET. Passive analog RF devices can include resistors, copper or aluminum inductors, high-value capacitors and electrically writable e-fuses for on-chip tuning. This process is normally for 1.2 or 1.5 V, but may be adapted for 2.5 or 3.3 V as well.

### Technology Selection and Packaging Issues

Both device manufacturers and system designers are investigating a wide range of choices in how they implement the various circuit functions. At one end of the spectrum are the proponents of single-chip solutions—all the functions of a particular application on one die. To date, most of the available single-chip devices have targeted relatively simple applications such as short-range ASK/OOK control devices (wireless weather stations, keyless entry, etc.) and Bluetooth (handsets and automotive systems).

Some of the devices advertised as "one chip" still require external components such as a front end filter, T/R switch or duplexer or IF filter. A few RFICs are promoted as having "all the radio functions" on a single chip, handing off a baseband signal to other portions of the system.

There are also many proponents of mixed technologies. For example, GaAs for switches and LNAs, SiGe for PLL and up/down conversion, and CMOS for baseband MPU, DSP and analog input/output. The ability to create an optimized design using such combinations is apparent, but manufacturability of the finished product would be much more difficult with a longer parts list and more complex assembly.

An intermediate solution can be achieved through creative packaging. Multiple functions are regularly placed into a single chip-like module. Technologies include multi-chip modules (MCMs) of various configurations, low-temperature co-fired ceramic (LTCC) assemblies, and multilayer structures using techniques similar to miniaturized PC board assembly. These device manufacturers' objective is to find the performance/price "sweet spots" that cannot be matched with either single-chip or more discrete assembly approaches.

Another issue is that the package has become part of the RFIC or MMIC component. Achieving the smallest die size and package footprint means that packaging must keep pace. As a result, there are many packaging choices for designers to consider—ultra-miniature conventional plastic packages, various leadless surface-mount packages and ball-grid array (BGA) packages. In addition, direct mounting of die has become more common, with customers buying die prepared for solder-bump mounting or wire bonding.

### Future Trends

Most observers see the continued trends of "smaller, better, cheaper" in wireless devices (and consumer electronics in general). To keep up, RFIC and MMIC makers are expected to keep working on their processes and packaging.

In markets where commodity-pricing is secondary to performance—e.g., base stations, instrumentation, and commercial products—steady, incremental improvements in the present building-block approach will meet many designers' requirements.

While high-volume customers are an important part of the RF/ microwave/optical market, there remain a large number of applications where the required quantities do not justify a dedicated RFIC solution. These moderate-volume products represent a significant market segment, albeit one that is generally not understood outside the professional community.

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