Philips takes on GaAs for phones with new generation silicon bipolars

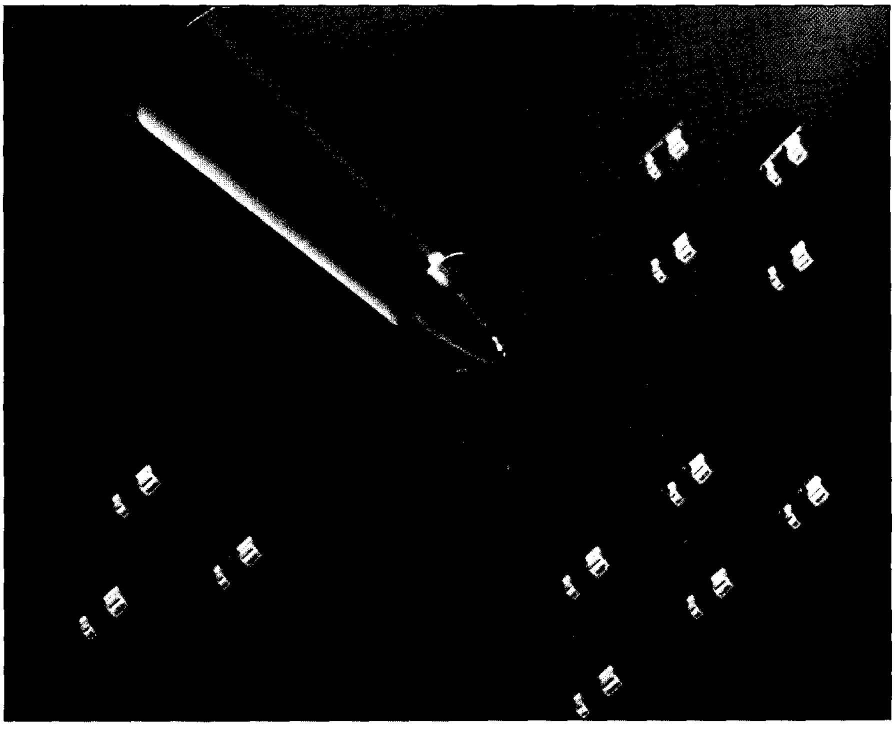
by Roy Szweda and Keith Gurnett

Philips Semiconductors recently announced its new range of "Fifth Generation" RF wideband transistors. The company claims that these silicon transistors meet the objectives of front-end receiver and RF transmitter sections of 3 V mobile phones with a "distinct price/performance ratio advantage over competing devices such as GaAs MESFETs". Not only do these devices achieve impressive performance, Philips is putting them into mass-production. Philips has developed a double-polysilicon process using LPCVD and has spent an extra $15 million equipping its fab in Nijmegen including new silicon epilayer equipment.

Talk-time on portable phone is crucially important and manufacturers are constantly striving to increase battery capacity and at the same time improve circuit efficiency. Philips is well aware of the need to reduce the amount of power that the handset draws from the battery. However, although the microphone, earpiece, keypad and display functions can all take advantage of very low power monolithic ICs, the RF sections of the phone — in particular its RF transmitter — remain power hungry.

To communicate reliably with a local base-station, the phone must be capable of transmitting at a specified power level. In the case of GSM phones, the required antenna power is 2 W. This means that the peak current drawn from the battery can be as high as 1.3 A. So one of today's greatest challenges for the design engineer must be to increase the efficiency of the RF power amplifier so that as little of the battery is wasted.

Cordless phone systems such as GSM operate at higher radio frequencies than analog systems, typically around 2 GHz. The performance limitations of silicon transistors meant that this mandated the use of GaAs components in the RF transmitter and receiver. Philips has one of the world's leading manufacturing facilities for GaAs components and recently joined forces with TriQuint Semiconductors, the Oregon-based leader in merchant supply of GaAs MMICs.



Philips Semiconductors' new Fifth Generation RF wideband transistors are optimised for use in hand-portable/mobile phones, pocket pagers and other wireless communications equipment.

Nevertheless, Philips has been pushing the performance of its bipolar silicon transistors in order to catch up

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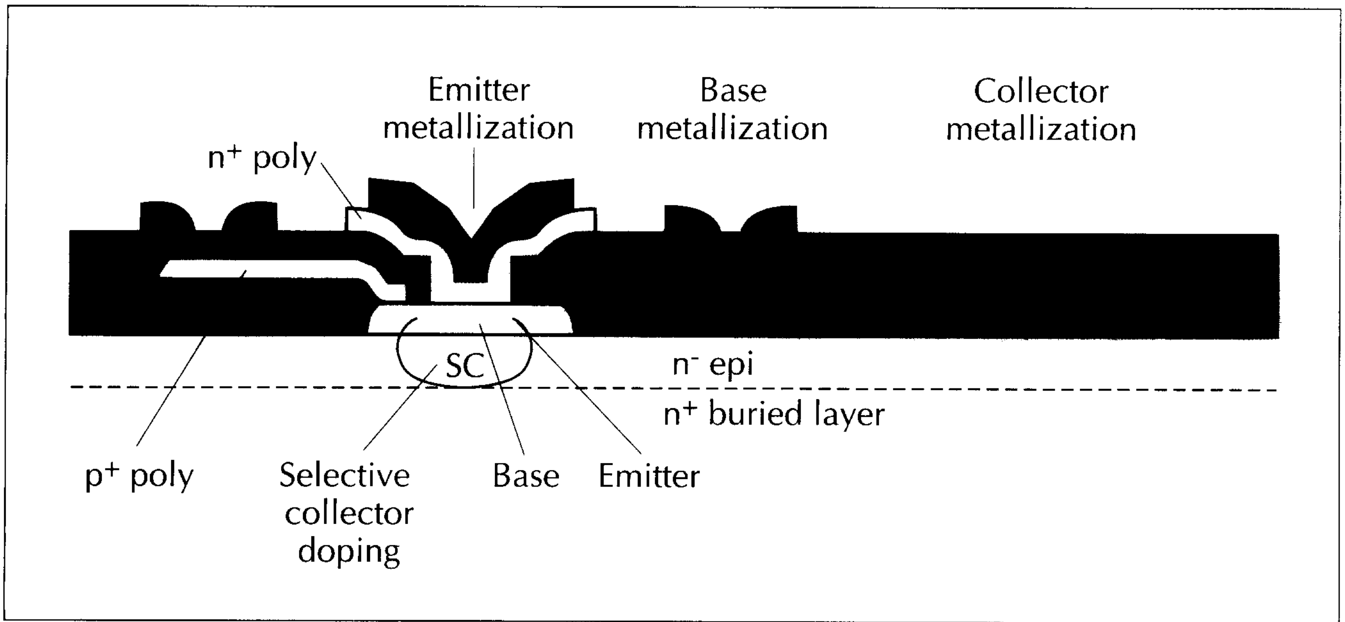

Figure 1. Base-widths of the order of 100 nm are needed for Philips' Fifth Generation RF transistors. These are achieved through a double-polysilicon (i.e. two LPCVD polysilicon layers) process shown here in cross-section (polysilicon is used in both base and emitter connections). The steep doping profiles of the base and emitter create the very narrow base width — typically 0.5 μm, required for high cut-off frequency by a self-aligned process. minimisation of base resistance is essential to achieve the very low noise figure — typically below 1.2 dB required in low-noise receivers.

with those of GaAs. In particular, it has introduced its "Fifth Generation" RF Wideband Transistor range. It claims that these offer comparable performance in terms of physical dimensions, weight and frequency performance but have the benefits that they are "much easier to use and offer a lower cost solution".

Bipolar not GaAs

Philips says that the new silicon transistors can be used everywhere in a mobile phone that GaAs devices would previously have been used. As a result it is using not only small-signal transistors suitable for the RF receiver but also medium-power ones for the power amplifier of the RF transmitter.

Moreover, the devices have usefully high gain — typically 22 dB at 2 GHz, which means that fewer devices are needed for the equivalent signal amplification. Philips says that when you couple this with a lower overall component count you get an overall reduction in the manufacturing cost of the handset.

The small signal devices have a very low noise figure — typically 1 dB, which allows the mobile phone to pick up very weak signals from the base-station. The user therefore gets better communications range and fewer drop-outs from atmospheric conditions and proximity to tall buildings, etc.

Meanwhile, the medium power devices have a very high power conversion — typically 60%, which reduces the battery power wastage in the power amplifier and lowers the heat output — this also means the transistors run cooler so their reliability and lifetime are enhanced.

Fab expansion

To support the mass production of the new transistors, Philips is expanding its Nijmegen wafer fab — already the largest of its kind in Europe — with a $15 million investment. As the Company puts it: "another step in Philips' plans to make the facility the world's leading source of discrete RF products and modules".

There are five separate fabs on the Nijmegen site with a production area of 3000 sq. m already up and running with Class-100 cleanrooms. The new investment will equip one of the fabs with new equipment for the double-polysilicon process for the Fifth Generation RF transistors. The first will be epitaxial layer deposition, RTA, fine line metal machines, and wafer test. RTA — rapid thermal annealing — is essential for the dopants implanted in the first polysilicon epilayer to achieve very steep doping profiles in the base and emitter regions. The new additions will also enable the company to develop small-scale integration RF circuits based on the same poly process.

Fabrication

Philips has developed a double-poly bipolar fabrication process to ensure optimum device performance. Figure 1 shows a cross-section of the process. To achieve cut-off frequencies of 25 GHz at voltages of 3 V or less, it is necessary to produce base widths of around 100 nm. A special approach was needed and in fact this process owes more to the way ICs are made than the traditional processes of discrete bipolar transistor manufacture.

Implicit in the double-poly process is a self-aligned base region. This ensures a high order of accuracy even at the very narrow base widths used here.

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In addition, lateral connection to the base region by p^+ polysilicon reduces the base resistance to give the very low noise figures required for low-noise applications. The lateral connection also minimises collector-base capacitance and in small-signal types allows designers to use single- rather than double-layer metallization (with its relaxed design rules) for emitter and base connections. Large area metallizations for the emitter allow the transistors to handle the high emitter current densities required in medium power types.

Fully tested devices will be packaged on site into ultra-small packages many of which have been specially developed by Philips.

Packaging is very important because of the need not only to sustain RF performance but also meet the ever tighter demands for miniaturisation from the mobile phone manufacturers. Their top-side construction — see Figure 2 — reduces series feedback and allows heat to be transferred via the emitter lead frame directly into the ground plane of the printed circuit board (PCB). Because no electrical isolation is required, the overall thermal resistance between transistor junctions and the PCB is typically less than 150 KW^{-1} for the medium power types.

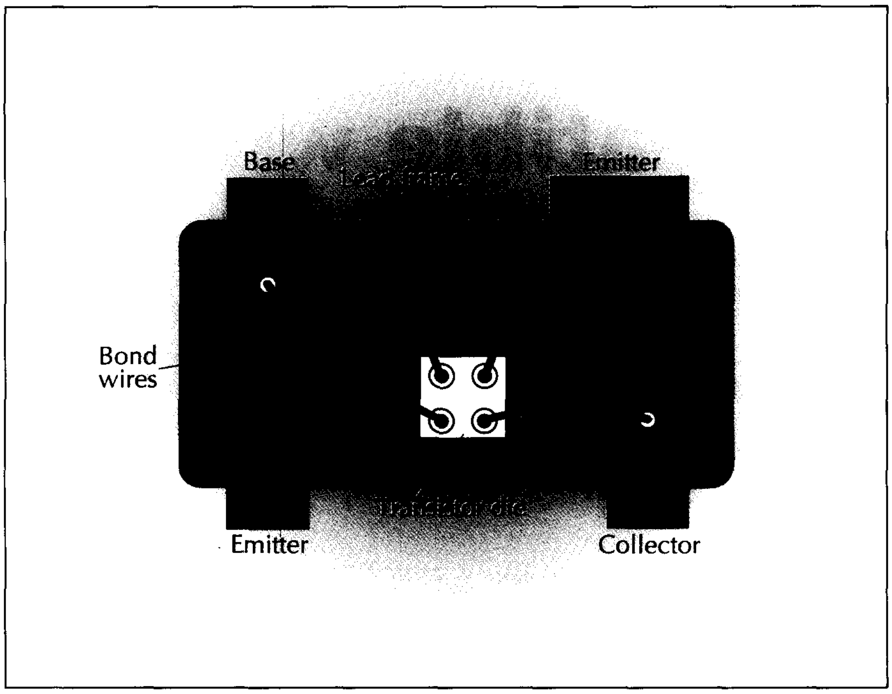

Figure 2. The top-side collector of the Philips RF transistor which uses a buried layer collector layer — see Figure 1 — and then mounts the transistor die "collector up". This not only maintains a low value of overall collector-base capacitance, but also minimises the length of the emitter bond-wire and hence reduces emitter inductance.

Generations of silicon

The latest generation of Philips' RF transistors are for use in the latest 1.6 GHz cordless and cellular phones. The devices are suitable for all stages of a mobile phone's RF transceiver, including its low-noise input amplifier, mixer, VCO and RF power amp driver. All types are optimised for use on 3 V supplies, but still perform as well at voltages as low as 1 V. Typical applications include DECT, PHS and DCS1800 handsets, satellite receivers and pocket pagers.

The previous generation of devices had transition frequencies of 9.5 GHz and gains of 13 dB at 2 GHz but the fifth generation feature double the transition frequency, gain improvements of between 5 dB and 8 dB and noise figures at 2 GHz as low as 1.2 dB. The ultra-small SOT343 surface mount (SM) packaging and specially designed internal lead frame help ensure optimum RF circuit performance and a significant reduction in PCB area.

Philips says that the transition frequencies of between 18 and 22 GHz are an order of magnitude greater than the operating frequencies of current wireless comms systems. When operated in common-emitter configurations at the optimum part of the gain bandwidth characteristic, the small signal types have gain values over 20 dB at a collector-emitter voltage of 3.6 V and a frequency of 2 GHz. Medium power types achieve power gains over 11 dB under similar operating conditions.

These factors mean that fewer stages are required in the phone's RF amplifiers which means reduced component count, lower power and a smaller handset.

Three small-signal devices will initially be available — the BFG403W, BFG410W and BFG425W — optimised for low voltage and have max f_T at collector currents of 3, 10 and 25 mA respectively. There are two initial devices in the medium-power series — the BFG480 and BFG21W — these have maximum f_T at 80 and 250 mA, respectively.

For example, the BFG21W in combination with the BFG425W is capable of delivering the 500 mW output needed for DECT phones. The 2-stage amplifier achieves overall power-added efficiency of over 50%. With the BFG21W operating at slightly higher quiescent current, the amplifier is ideal for use in handsets that need excellent linearity performance such as those designed for the Japanese PHS system.

In volume the devices are priced at under 30 cents for the small-signal types and under 45 cents for the medium power types.

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