# Wireless-Trench technology for portable wireless applications

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**Until recently, the use of silicon for the production of wireless integrated power amplifiers has not been viable. Here, however, the author describes how a revolutionary new grounding method makes this technique possible.**

**Wireless-Trench technology was first applied to an integrated power output amplifier for the DECT system—a digital wireless standard for home and office handsets. Using this same technical approach, Ericsson is currently developing a family of related power amplifier products for GSM 900 and 1800/1900MHz as well as GSM dual/triple-band, PDC, other cordless systems, and Bluetooth.**

**TRADEMARKS**

Wireless-Trench technology and the Bluetooth trademarks are owned by Telefonaktiebolaget LM Ericsson, Sweden.

**BOX A, TERMS AND ABBREVIATIONS**

| | |
|---|---|
| DECT | Digital enhanced cordless telecommunications |
| $f_T$ | Maximum transition frequency |
| GaAs | Gallium-arsenide |
| GSM | Global system for mobile communication |
| HBT | Heterojunction bipolar transistor |
| LDMOS | Laterally-diffused metal oxide semiconductor transistor |
| MESFET | Metal semiconductor field-effect transistor |
| NPN | N-type/P-type/N-type |
| PA | Power amplifier |
| PAE | Power-added efficiency |
| PDC | Personal digital communication |
| $P_{in}$ | Input power |
| PNP | P-type/N-type/P-type |
| $P_{out}$ | Output power |
| QSOP | Quad small outline package |
| RF-IC | Radio frequency integrated circuit |
| SEM | Scanning electron microscopy |
| Si | Silicon |
| SiGe | Silicon-germanium |
| $V_{cc}$ | Supply voltage |
| VSWR | Voltage standing-wave ratio |

An important rule of thumb often used by radio circuit designers says that a maximum transition frequency ($f_T$)—a general figure of merit for any high-frequency transistor—of at least ten times the operating frequency for the active device is needed to design a smoothly running radio frequency (RF) circuit for modern wireless applications. While this may be true for elementary radio building blocks, the design of the output power amplifier (PA) puts additional requirements on the semiconductor process, thus precluding the use of silicon processes for the power amplifier. For this reason, gallium-arsenide (GaAs) metal semiconductor field-effect transistors (MESFET) and other more advanced technologies have been widely in use in this area up to the present time.

As the wireless communication business continues to grow, there is a great demand for reducing the price of all system parts, as well as for using semiconductor manufacturing processes that can handle very high volumes during the short product cycles of many of the new "gadgets." Silicon bipolar integrated circuit technology (RF-IC) is one suitable candidate for non-digital parts. With today's production processes offering an $f_T$ in the 25 GHz range and higher, silicon can even fulfill the technical requirements needed for power amplifiers. The use of RF-IC technology also facilitates the integration of more functionality in power amplifiers. In particular, power control and active linearization are two important features needed for evolving second-generation and soon-to-arrive third-generation systems.

Ericsson Microelectronics has long enjoyed a good reputation for its development of high-power bipolar and discrete laterally-diffused metal oxide semiconductor transistors (LDMOS) for cellular base stations. As a provider of low-voltage RF-IC and GaAs power amplifiers within Ericsson, and lately for use on the Bluetooth market, the company has wide access to the know-how and technology required to manufacture silicon power amplifiers for high-volume applications. Ericsson Microelectronics has gained this know-how through its own development and in-house production, as well as through its partnerships with other vendors. Today, this wealth of experience is being used to explore silicon RF-IC technology for power amplifiers.

## Grounding: the essential element for power amplifier performance

One of the most important factors for achieving high performance in power amplifiers is being able to provide a good conducting path from the active devices to ground. The straightforward solution is to use many bonding wires from the chip's surface to the package. Preferably this includes a grounded lead frame, maybe even with a number of the pins permanently connected (fused) to outside ground connections on the circuit board, or a package in which the back side of the lead frame is exposed and soldered directly to the circuit board.

However, at these high frequencies, the bonding wire from the chip to the package severely limits the circuit's performance. To achieve low resistance and low impedance to ground, the number of ground bonding wires is increased; but since a power amplifier is usually quite a small circuit, the additional pads needed for bonding increases the size of the chip considerably, which can prove to be very costly. Packages with exposed lead frames represent no immediate solution to the bonding wire problem, since they are also considerably expensive.

## Device technology

The semiconductor process used for Ericsson's silicon power amplifiers is a half-micron, 25 GHz $f_T$ double-polysilicon bipolar process with additional features for improved wireless performance. This process allows operation up to 5 V and includes NPN and PNP transistors for use in analog and digital designs. For the integrated internal matching network, on-chip capacitors and inductors are used. Four layers of metalization (with a thick top layer for improved performance of the integrated inductors) are deployed. Advanced, deep-trench isolation is used to obtain small-sized, low-parasitic, high-performance transistors. Figure 1 shows a schematic view of a trench-isolated bipolar NPN transistor.

## Wireless-Trench technology

As was pointed out above, a good ground connection is essential for power amplifiers. In addition to the bonding wires, the substrate (the back side of the die) is usually connected to ground (the package), which enables the use of contacts at the chip surface for ground connection. The contacts consist of metal on highly doped semiconductor material. To achieve low resistance, a high processing temperature and long processing time are required. A contact of this type might have to occupy a considerable area to achieve low contact resistance. Furthermore, the semiconductor structure with which it maintains contact consists of several medium-doped layers on the original substrate with more resistance adding up in the current path as a result. In many RF-IC processes, the substrate itself is low-doped, which precludes its use as a low-resistance path to ground.

In Ericsson's RF-IC process for power amplifiers, the substrate selected is as highly doped as possible, close to the solubility limit. Used together with deep trench isolation, the circuit achieves excellent protection against latch-up effects, which might occur in devices that switch large currents, such as power amplifiers.

To assure excellent grounding from the active device to the highly doped semiconductor substrate and the package, a new type of tungsten-metalized substrate contacts have been developed for the front side. These contacts are formed by etching additional deep trenches through the medium-doped upper silicon layers down to the highly doped substrate, filling the trenches with a barrier material, which is annealed for a short time to form a good metal-to-semiconductor contact, finally filling them with tungsten. The new process module is fully compatible with conventional RF-IC processing, and adds only a few more steps to the process flow.

Figure 2 shows a scanning electron microscopy photograph of a double NPN-transistor structure with its deep trench isolation to the left, and the new trench sub-

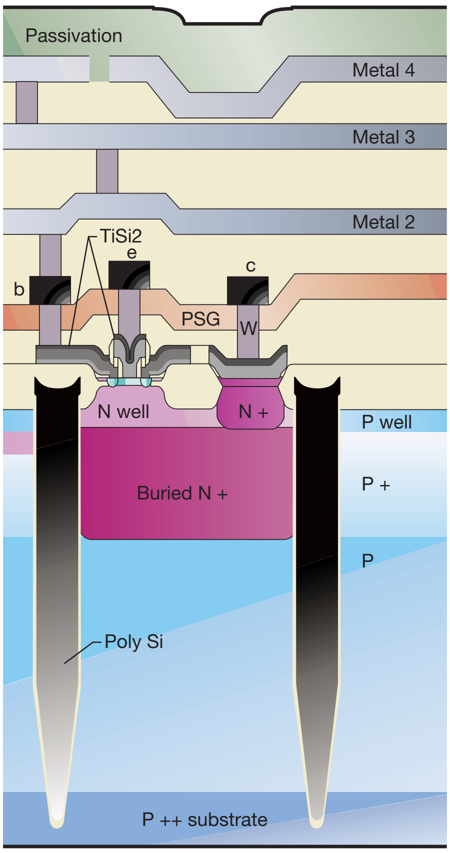


**Figure 1**
**Cross-section of trench-isolated NPN transistor.**

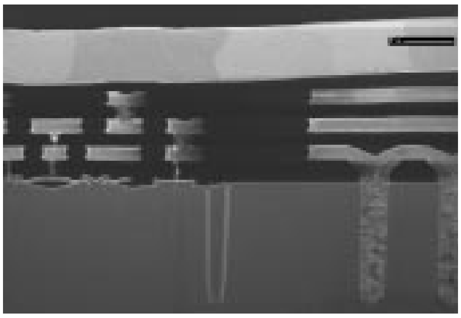


**Figure 2**
**Scanning electron microscopy (SEM) photograph of double NPN transistor with new trench substrate contact to the right.**

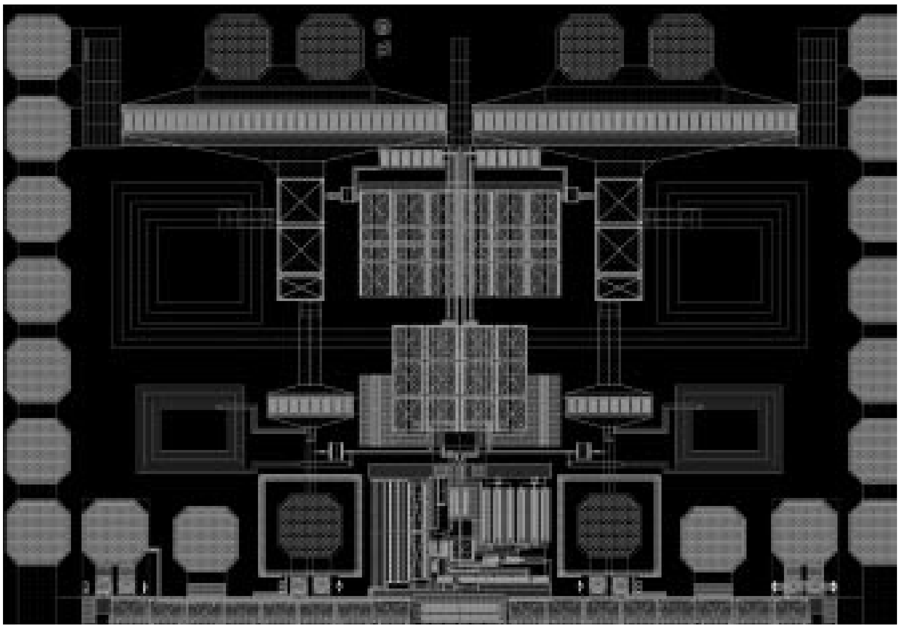
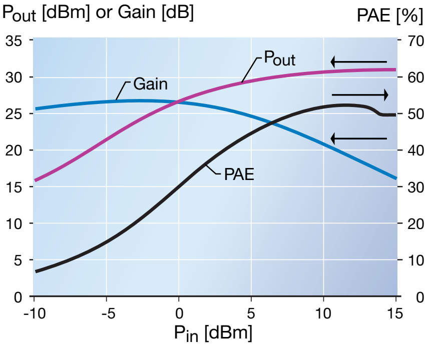


**Figure 3**
**The PBL 403 09 DECT power amplifier chip. Actual chip size is 1.3 x 1.0 mm.**

**Figure 4**
**$P_{out}$, gain and PAE vs. $P_{in}$ at $V_{cc}$ = 3.6 V for DECT power amplifier.**



strate contact to the right. Since almost all of the total resistance from the front to the back of the wafer is contained in the top layers—now penetrated by the metal-filled trench—a good ground reference plane and low resistance path to the package are obtained within the chip. Each contact occupies very little area (around one square micron), and can be used in large arrays anywhere on unoccupied circuit areas, say, between blocks or under metalization, to ensure excellent grounding for each part of the circuit. Furthermore, the impedance to ground is now mainly resistive, instead of inductive as is the case when many bonding wires are used. The substrate contacts can also be used to improve shielding and reduce crosstalk between different circuit blocks. In the future, this may prove to be crucial to the integration of radio or control circuitry into the power amplifier chip.

But the greatest potential of the new substrate contact was yet to be demonstrated. If the new metal-filled substrate contact, which provides ground connections from the substrate up to the circuit, is as low-resistive as expected, it should even be possible to use it as a current path from the circuit to ground, instead of the many ground bonding wires usually required in a good power amplifier design. To explore this hypothesis, an experiment was undertaken. A chip used for the DECT power amplifier PBL 403 09 (Figure 3), designed with the new substrate contacts from the beginning, was mounted in an open QSOP16 package. A total of 22 bonding wires were used in this design: fourteen for ground, and eight for supply voltage, input/output signals, and so on. The back-side contact from the chip to the package was of good quality and low-ohmic. The circuit was mounted on its evaluation board, and input/output matching was tuned for optimum performance. The ground bonding wires were then carefully removed, one by one, using a stereomicroscope. When the first wires were removed, the RF performance did not change. With all the ground wires removed, RF performance still remained virtually unchanged. This experiment shows that it is possible to operate a power amplifier without any bonding wires to ground (bringing new meaning to the term *wireless*!) using this new trench substrate contact.

By permanently eliminating the bonding wires to ground, considerable pad area is saved (20% of the chip area for DECT power amplifier), and bonding the chip is simplified (eight wires instead of 22 in the same example). It also becomes possible to select a smaller and cheaper package, thus saving costs and space without any degradation of performance.

This new, unique feature of Ericsson Microelectronics' family of power amplifiers for wireless applications has been dubbed Wireless-Trench technology. Several patents already cover the fabrication and use of the metalized trench contacts.

## First application: silicon DECT power amplifier

Wireless-Trench technology was first applied to an integrated power output amplifier for the DECT system. DECT is a digital wireless standard for home and office handsets. Using maximum power of around 0.5 W (27 dBm), the standard communicates at 1.9 GHz, transmitting only 1/24 of the time. The power level and general requirements for the power amplifier are simpler to meet as compared with, say, GSM. A DECT power amplifier was therefore a good starting point for testing the potential of the new silicon RF-IC technology; thus it was chosen as the first product in the new family of silicon-integrated power amplifiers for low-voltage, wireless applications that will be introduced by Ericsson Microelectronics in the near future.

The PBL 403 09 integrated DECT power amplifier, which is housed in a fused QSOP16 package, delivers up to 30 dBm (1 W) of output power at 1900 MHz, with more than 50% power-added efficiency (PAE) The device can be operated up to a 100% duty cycle with minimum performance degradation. Input and output are of the differential type.

Figure 4 shows the input/output characteristics. The two-stage integrated amplifier has on-chip input and inter-stage matching (50 ohms at the input). It also contains biasing circuitry and on/off control signal, and operates using a single 3.6 V supply. It can withstand more than the 5 V supply voltage that occasionally occurs in systems during battery charging, besides withstanding open/short voltage standing-wave ratio (VSWR) conditions to over 5 V with no failures or degradation.

The PBL 403 09 power amplifier is specially designed to interface easily with the PBL 402 15 transceiver chip for DECT. The transceiver has a differential output that interfaces with the power amplifier (using only capacitors for DC-blocking purposes); it also delivers the on/off control signal with appropriate timing. Figure 5 shows how easily the power amplifier is interfaced with the transceiver to form the radio part of a DECT handset or base unit.

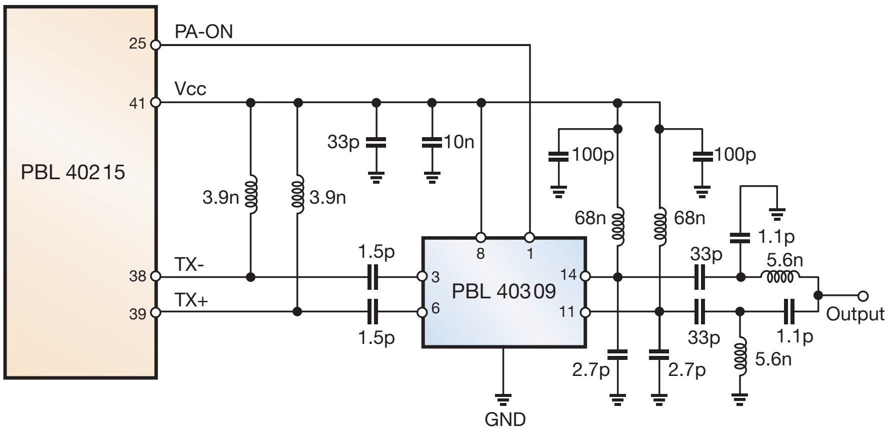


**Figure 5**
**DECT radio with PBL 402 15 transceiver and PBL 403 09 power amplifier.**

The PBL 403 09 silicon power amplifier matches the performance of comparable GaAs products—typically, GaAs products show efficiency in the 40% range, with up to 55% for a few high-performance designs using heterojunction-bipolar-transistor (HBT) technology—Si (35%) and SiGe (30% to 40%). The use of conventional silicon technology makes the use of negative bias or battery switches unnecessary, in contrast to most of the GaAs products that are currently available.

## What's next?

Using the same technical approach as was used for the PBL 403 09, Ericsson is currently developing a family of related power amplifier products for GSM 900 and 1800/1900 MHz as well as GSM dual/triple-band, PDC, other cordless systems, and Bluetooth. Figure 6 shows the electrical data for a pre-production sample of the PBL 403 10, a single-ended power amplifier for 900 MHz GSM. At 3.4 V supply voltage, the amplifier delivers 35.5 dBm output power with more than 55% efficiency and 31 dB of small-signal gain. The power amplifier, which is a two-stage integrated amplifier designed for 2.7 to 5 V single-supply operation, has integrated input and inter-stage matching and analog input for the power ramp. In power-down mode, it consumes less than 10 µA of standby current. In addition, this single-ended amplifier uses Wireless-Trench technology, which means that it can be operated without ground wires, and without limits to its performance. Similar impressive results have been demonstrated with power amplifiers for other wireless systems.

## Conclusion

The results obtained for power amplifiers designed with the new Wireless-Trench technology, as presented in this article, prove the capability of the new technology for low-cost, high-performance wireless power applications. Moreover, this marks the entrance of silicon into power amplifiers—an area that has been dominated by GaAs technologies.

**Figure 6**
**$P_{out}$, gain and PAE vs. $P_{in}$ at $V_{cc}$ = 3.4 V for GSM 900 power amplifier.**