Highly-Integrated Radio Frequency Integrated Circuits (RFICs) for UMTS

Robert Weigel, Senior Member IEEE
Institut für Nachrichtentechnik/Informationstechnik
Universität Linz, A-4040 Linz, Austria
&
DICE Danube Integrated Circuit Engineering GmbH & Co KG
A-4040 Linz, Austria

This paper will report on the RF-related system and radio frequency integrated circuit (RFIC) issues of 3G W-CDMA systems like UMTS, technologies that will play a major role in the future of wireless telecommunications allowing for networks which will add broadband data to support video, Internet access, and other high speed data services for untethered devices. It will also address the founding of the company DICE in Linz as an Infineon Technologies Development Center.

1. Introduction

The radio frequency integrated circuit (RFIC) market has suddenly expanded to unimaginable dimensions. Especially wireless devices such as cellular and cordless phones, pagers, global positioning system (GPS) devices, and RF identification tags are rapidly penetrating all aspects of our lives, evolving from luxury items to indispensable tools. The source for the establishment of this new RFIC market can be traced back to a technology push/market pull situation in Europe about ten years ago: at that time, (i) the semiconductor industry had developed low-cost silicon production facilities to mass-produce bipolar transistors with 10 GHz transit frequency and pushed the creation of a new market for this technology; (ii) the European telecommunication industry had just defined the dictionary and grammar for the GSM digital mobile communication system (GSM: Group Special Mobile) requiring for high-fidelity, low-cost chip solutions to produce small, light-weight mobiles at consumer prices. In the following years, both the commercial market for cellular phones and the silicon technology were growing in a harmonic environment orchestrated by the European commission and the European wireless standards organization ETSI. The European GSM story of success has played the major role in the tremendous worldwide increase of the number of subscribers and furthermore pushed the development of other mobile communication systems in the U.S. and in Japan. It is expected that the upcoming advent of the Universal Mobile Telecommunications System (UMTS) will refuel the growing RFIC market expansion.

2. RF Transceiver Architectures and RFIC Technologies

Today's pocket phones contain more than one million transistors, with only a small fraction operating in the RF range and the rest performing low-frequency baseband signal processing. In other words, the baseband section is, in terms of number of devices, yet several orders of magnitude more complex than the RF section. On the other side however, the RF section is still the design bottleneck of the entire system due to the fact that it demands a good understanding of disciplines that are not directly related to IC design such as communication theory, microwave theory, computer-aided design, multiple access, signal propagation, theory of random signals, wireless standards, and transceiver architectures [1]. As is typical for cellular phone systems standardization, sufficient RF performance has been assumed also in the W-CDMA (Wideband Code Division Multiple Access) standardization phase for UMTS, and most efforts have been put to baseband issues. However, one has recognized meanwhile that much more attention has to be paid to the RF part of the pocket phone transceiver since it strongly influences the overall digital system performance. Thus, in the RF concept engineering of today's commercial products with their short time-to-market requirements, a prediction of the needed RF performance by using RF system simulation is meanwhile indispensable [2], [3]. This is in particular the case with the third generation (3G) W-CDMA system UMTS which, from the design point of view, is quite different from second generation (2G) systems like GSM due to the fact that the users are now separated in the power domain (using codes) rather than being separated in the time and/or frequency domain. Concerning UMTS RF transceiver architectures, complexity, cost, power dissipation, the number of external components, and, of course, the expertise of each manufacturer's RF design team are the primary criteria as is the case with any wireless system concept. As IC technologies evolve, the relative importance of each of these criteria changes, allowing approaches that once seemed impractical to return as plausible solutions. Today, the worldwide GSM RFIC market is mainly penetrated by superheterodyne I/Q receivers (80%) and homodyne I/Q receivers (15%) on the receiver (RX) side, and by, respectively, heterodyne upconversion modulation loop concepts (55%), heterodyne low IF/upconversion concepts (25%), and direct modulation concepts (10%) on the transmitter (TX) side. In the upcoming UMTS market, we will probably have a quite different market situation. Due to the results achieved by an extensive system simulation work we have done recently, it is likely that homodyne receiving combined with heterodyne transmitting will soon attain the highest market penetration although the first UMTS receivers that will appear this May on the Japanese market will be heterodyne receivers.

Today, mobile phone RFICs are mostly fabricated from BiCMOS technologies as is currently the case with RFICs for UMTS. Since the SiGe technology is now available at nearly the same wafer cost as silicon RF-bipolar technology, SiGe bipolar transistor technology combined with massive digital integration of CMOS might be the commercial solution for the next generation of UMTS RFIC's which will appear on the European market in about one year. The further roadmap is however somewhat unclear. R&D engineers and managers never stop thinking about new IC technologies such as SOI CMOS, RF CMOS, and silicon-carbide bipolar technologies associated with new technologies in the metalization and insulator arena. This plurality of technology innovations introduces extreme problems for the RFIC manufacturers since any strategic mistake made in their technology roadmaps can have severe consequences in the highly competitive market of the next RFIC product generation. Again, RF system simulation taking into account both RF architecture and IC technology aspects is becoming an important key to attack and solve this technology dilemma, at least to lower the risk when selecting a specific technology. Without system simulation we would not have been able to release the worldwide first operable RFIC's for UMTS applications [4].

3. RFICs For Heterodyne Transceiver Architectures

Reference [4] reports on our work resulting in fully integrated silicon bipolar intermediate frequency (IF) receiver and transmitter chips in various versions. All chips come in a small outline leadless package and incorporate an on-chip IF synthesizer with on-chip VCO tuning and tank as well as $6^{th}/5^{th}$ order baseband filters. The chips comply with the Japanese ARIB W-CDMA and the European UMTS standards. As an example, Fig. 1 gives the layout of one of the receiver chips.

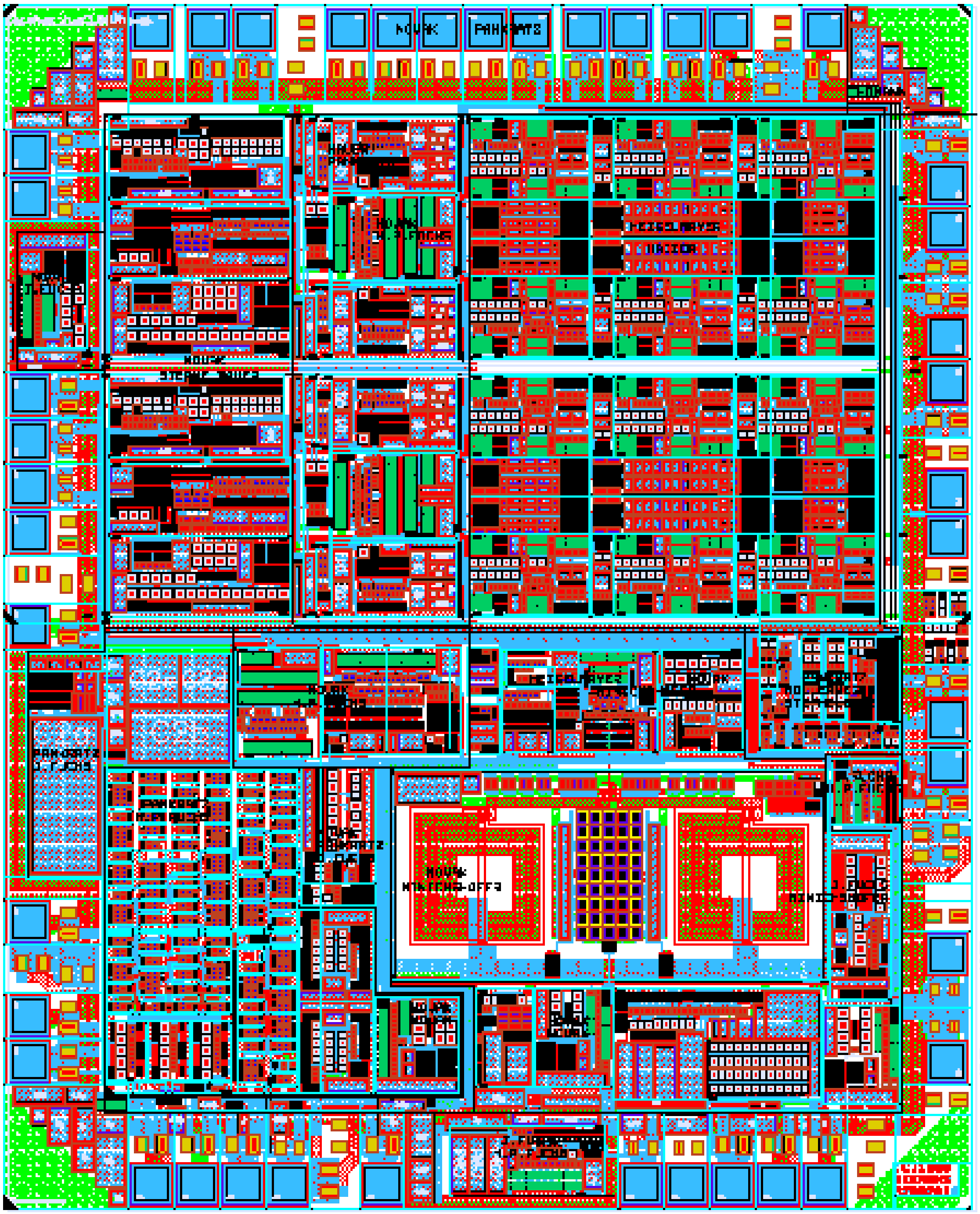

Fig. 1: Layout of a highly-integrated IF receiver RFIC.

The synthesizer is located in the lower part. The reference divider, the phase comparator and the charge pump are located in the lower left corner, and the on-chip VCO, voltage regulator and biasing in the lower right corner, respectively. VCO buffer, the LO divider and some more biasing is located just above the VCO. In the upper part two identical receiver paths are stacked vertically. The block visible far to the left is the IF variable gain amplifier, the block left to the center is the demodulator, and the block to the right contains the I/Q baseband filters. The chips are fabricated from Infineon's 0.4µm/ 25 GHz silicon bipolar process. IF receiver and IF transmitter die size is 2.33 mm x 2.9 mm. The devices are designed for low external component count and operate at 2.7 – 3.3 V supply, an ambient temperature of –30 to +85 °C, and incorporate several power-down modes for efficient use in mobiles. The receiver includes two complete IF paths for antenna diversity/service channel monitoring and a common LO generation and distribution. Any of our IF receiver and IF transmitter RFICs is a highly integrated RFIC device which completely fulfills all system requirements defined by the Japanese and European standards with sufficient reserve.

4. RFICs For Homodyne Transceiver Architectures

We have designed the heterodyne chip set reported on above in order to be able to serve the first generation UMTS market with low risk. The next generation UMTS transceivers however will rely on homodyne solutions probably using SiGe bipolar technologies. Our first design results demonstrate clearly that the many problems associated with homodyne receivers such as DC offsets, I/Q mismatch, even-order distortion, flicker noise, and LO leakage can be solved satisfactorily [5], [6], i.e. the advanced SiGe technology is mature for this approach which is extremely attractive from the techno-economic point of view since direct RF-to-baseband conversion, e.g., avoids the need for discrete surface acoustic wave (SAW) filters as external IF components.

5. Conclusion

Exchange and cross licensing of intellectual property (IP) is one key to strengthen further the European positioning in the global RFIC markets. The other key is the availability of well-trained RF designers. The latter issue has guided our initiative to start an intensive collaborative research work between the University of Linz and Infineon Technologies in July 1998 which has led to the spin-off foundation of the company DICE in Linz in August 1999; in January 2000 Infineon Technologies has joint DICE. The founding of the high-technology company DICE [http://www.dice.at] is an excellent example for a successful technology transfer from university to industry.

References

[1] B. Razavi, "*RF Microelectronics*", Prentice Hall, 1998.

[2] R. Weigel, L. Maurer, D. Pimingsdorfer, A. Springer, "*RF Transceiver Architectures for W-CDMA Systems Like UMTS: State of the Art and Future Trends*", Proceedings International Symposium on Acoustic Wave Devices for Future Mobile Communication Systems, Chiba, Japan, pp. 25 – 34, March 2001 (Invited Paper).

[3] L. Maurer, M. Huemer, D. Pimingsdorfer, A. Springer, R. Weigel, "*Third Generation Wideband CDMA Systems Like UMTS*", University of Linz Proceedings, pp. 1 – 188, January 2001 (Full-Day Tutorial).

[4] W. Thomann, J. Fenk, R. Hagelauer, R. Weigel, "*Fully Integrated W-CDMA IF Receiver and Transmitter including IF Synthesizer and on-chip VCO for UMTS Mobiles*", Proceedings IEEE Bipolar/BiCMOS Circuits and Technology Meeting, Minneapolis, USA, pp. 36 – 39, September 2000.

[5] H. Pretl, W. Schelmbauer, B. Adler, L. Maurer, J. Fenk, R. Weigel, "*A Down-Conversion Mixer for a UMTS Zero-IF Receiver in 75 GHz SiGe-Bipolar Technology*", Proceedings IEEE Bipolar/BiCMOS Circuits and Technology Meeting, Minneapolis, USA, pp. 40 – 43, September 2000.

[6] W. Schelmbauer, H. Pretl, L. Maurer, R. Weigel, "*A Fully Integrated Analog Baseband IC for an UMTS Zero-IF Receiver*", Proceedings Austrochip, Graz, Austria, pp. 8 – 15, October 2000.