How to Build a Radio on a Chip

I study design techniques that will allow people to build inexpensive miniature radios with a single silicon chip and a couple of other small components. I also study ways of reducing the power consumption of such radios so that they may be used in portable devices that require a long battery life. I expect that this work will lead to new applications where miniature, low-cost radios will be incorporated into everyday devices and appliances. This will enable new, useful applications in areas such as ambulatory health monitoring, building & environmental monitoring, inventory management, wireless Internet access, and home and factory automation. I hope that the impact of small, inexpensive single-chip radios will be no less than that of the microprocessor revolution, which made microprocessor-controlled devices so pervasive in today's world.

Some are called smart tags, others Radios-on-a-Chip (ROCs), some other go by code names such as IEEE-802.11 or Bluetooth. These wireless devices allow communication between all computers, handheld devices and peripherals. They give us the freedom to roam about the building with our laptops, portable digital assistants (PDAs), pagers, etc. But what are these wireless devices, and why should we care about them?

With current silicon technology it is possible to fit all the major components of a radio transmitter and receiver in a millimeter square of area, i.e., no larger than the head of a pin. A chip radio of this size will cost about 10 cents to manufacture. The small cost of this device opens up possibilities for use in applications not possible before because they were too expensive. The main problem is that in a typical radio receiver, a significant amount of power is used by what is called the local oscillator (LO). The LO generates a high frequency signal used to detect the signal we are interested in receiving. To receive different channels, we need to control very precisely the frequency of the LO. This is usually done using a frequency synthesizer. The frequency synthesizer is also an important component of a radio transmitter.

A frequency synthesizer is composed of an oscillator (LO), frequency divider, and a phase detector. In essence, the oscillator's frequency tracks the frequency of a quartz crystal, but at a multiple of the frequency divider ratio. So, for example, if the crystal is oscillating at 10 MHz and the divider is set to divide by 100, the oscillator frequency becomes 1000 MHz.

My main research goal is to develop techniques that will allow the design and construction of a very small radio receiver that fits on a single 1-mm squared silicon chip and will be suitable for low-cost applications. To accomplish this goal, we must be able to integrate all the components of a frequency synthesizer suitable for a radio into a single chip. This task is a challenge. Also, the synthesizer uses a significant amount of power. Minimizing the power required by the synthesizer will have a great impact in reducing the power used by the whole radio receiver, thus significantly increasing the battery life. For these reasons, we are studying how to minimize the power usage of the synthesizer with a special emphasis in the oscillator and frequency dividers.

A ring oscillator is very small and easy to integrate into a chip. We studied the properties of different kinds of ring oscillators and their suitability for use in a frequency synthesizer. We also studied how to use ring oscillators as frequency dividers. Conventional frequency dividers use more power as their division ratio increases, i.e., dividing the frequency by 8 requires more power than dividing it by 4. We are studying a technique that has the opposite behavior, i.e., division by 8 uses less power than division by 4. This technique called injection locking promises power savings of up to a factor of ten in the frequency divider alone.

Applications that will benefit the most from this technology require the radios to be within 10 meters while using the 900-MHz frequency band commonly used in cordless phones. Many applications also need the radio to operate for hundreds of hours using only a small battery. For instance, a pacemaker could communicate with a PDA and send an alarm to the hospital over the Internet. We could also monitor the health condition of a baby in-utero. A smart sensor could be embedded into a building constantly monitoring the stress in the structure. Disposable merchandise tags could be interrogated wirelessly in a store allowing instant inventory counts. The applications are virtually endless.

