# Control in Mobile Phones

Mobile phones have made a huge impact on the world in a short time period. They are now affordable for those with daily incomes as low as a dollar, and they have brought communication infrastructure to new areas. In addition to enabling convenient and low-cost telephone services, mobile phones have also made information available at subscribers' fingertips. For many, their first contact with the Internet is with a mobile phone, not a computer.

Mobile phones as affordable and attractive consumer products would not be possible without control. Each phone has at least a half dozen function-critical control loops. Control is used to reduce cost, size, and power consumption to levels where mass-produced, battery-operated products are feasible.

With a world penetration of 4 billion users, the number of control loops in mobile phones is in the range of $10^{10}$ to $10^{11}$. If you choose any control loop in the world at random, it is likely located in a mobile phone, making the application area one of the major success stories of control in recent times. The area is heavily patented, with thousands of new patents granted each year, a large share of them describing control inventions.

## Access Control

Each phone contains a transceiver unit that makes radio access possible with one or several base stations. Designing a low-cost transceiver that is easy to mass produce and has sufficient power efficiency, receiver sensitivity, and linearity is a major technical challenge. Some of the control loops that have enabled transceiver design with the technology components available today are automatic gain control (AGC), automatic frequency control (AFC), transmission power control, timing control, and feedback control of coding and modulation.



Radio Unit

Application CPU
Access CPU

*Radio Unit Clock Rate: ~2 GHz*
*Application and Access CPU: ~500 MHz*
*Memory: 512 MB RAM + 1 GB Flash*
*(data for high-end phones)*

## Circuit Design Level Control

Control loops are also heavily used on the electronic circuit design level, for example, in the design of low-noise amplifiers (LNAs), voltage conversion units, operational amplifiers, and power-efficient sigma-delta analog-to-digital and digital-to-analog converters. Feedback control on the circuit level is typically used to compensate for component variations due to temperature, voltage, and aging.

## Application Control

In mobile telephones, application control refers to the control of on-device resources. Boundaries between mobile phones and computers are disappearing. A major challenge is to facilitate distributed application development on scalable architectures, where the amount of available computational resources, memory, and power is unknown until runtime. Thus, feedback control loops are also becoming important for controlling computational resources in mobile phones. Reliable temperature control is also important for products that lack the ability to survive critical situations by starting a cooling mechanism such as a fan.



*Control has been embedded in mobile telephones since the first large, bulky, barely portable handsets and continues to be a key technology for today's smart phones (images not to scale).*

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## Power Control

In the most-used version (WCDMA FDD) of the 3G radio standard introduced at the beginning of the millennium, all mobile phones in a radio cell transmit simultaneously on the same frequency. A clever design of the coding scheme makes it possible to filter out and amplify the wanted part of the received signal. All other transmissions will act as noise. Thus, controlling the power of all transmitted signals is critical; failed power control in one mobile can destroy the operation of an entire cell.

The base station (BS) and mobile phones cooperate to control both the downlink signal power (BS to mobile) and uplink signal power (mobile to BS) using two control loops. An interesting coupling between these loops arises because failure in downlink control will have an impact on the communication of control commands for the uplink power, and vice versa.
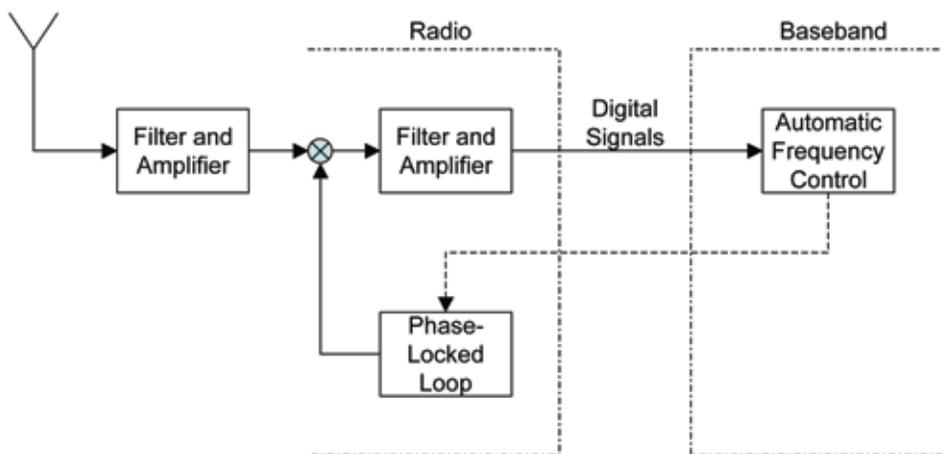
Because the controller includes integral action, anti-windup control must be used when the control loop is broken. The 3G standard includes tests for proper anti-windup. An interesting control situation also occurs during the so-called "soft handover," when several base stations simultaneously try to control the output power of the mobile.

## Automatic Frequency Control (AFC)

For correct reception of radio signals, the local oscillator in the mobile phone must have the same frequency as the signal to be received. The relative frequency accuracy targeted for good reception is on the order of 0.01 to 0.1 parts per million (ppm).

Without feedback control, achieving this specification would require crystal oscillators with high power consumption. The crystal oscillators would also be large and expensive. The accuracy achievable with open-loop control and at reasonable cost is on the order of 10 ppm today. Thus feedback extends the technological frontier by a factor of 1000. The main disturbances for which feedback is essential are due to temperature variations, the Doppler effect for moving users, variations over battery voltage, and oscillator frequency and aging.

The AFC control loop locks the oscillator phase to the phase of the received radio signal using known transmitted signals, digital "pilot" symbols. The controller can be of proportional-integral (PI) type, and the main design tradeoff is to achieve good noise rejection and fast tracking of frequency variations simultaneously. Gain scheduling is typically used, with faster control for rapidly moving phones.



*Mobile phones include a radio unit, which works with analog signals at high frequencies using analog circuits, and a baseband unit, which works with digital signals using digital hardware blocks and special-purpose digital signal processors. Automatic frequency control thus controls the analog phase-locked loop using digital symbols.*

## Automatic Gain Control (AGC)

The strength of the received signal shows large variations depending on the distance from the transmitter to the receiver. The receiver must show linear behavior for an operating range between -25 and -115 dBm (where 0 dBm equals 1 mW); that is, a $10^9$ power change on the input (comparable to the power ratio between a lamp and a nuclear power plant).

Low-cost electronic components with such dynamic range are not feasible today. Feedback is used in several stages to control the gain of each block in the receiver chain so that the output signal fits the dynamic range of the succeeding block. The AGC loops must be sufficiently fast to track channel propagation variations. A PI controller with gain scheduling is often used.