

Minimizing the electrical real estate

A popular science summary of the master thesis: "Direct Conversion Front End for LTE and LTE-A with Frequency-Translational Feedback, Harmonic Rejection Mixer and Input Matching Compensation," By Douglas Andersson Hågglund

Imagine that you want to build a house. You start by thinking out what functions you want the house to fulfill and proceed by solving all the difficult issues in building a house. Next you find and buy a plot of land just large enough to fit your dream home. Soon enough you find out that the local building code requires all plots to be covered by a largely useless sandbox. Sighing, you also realize that it has to be the same size as the house and that you need to buy a plot of double size. Now imagine that instead of plots of land we are talking about integrated circuits with an area close to one hundredth of a fingernail. Instead of sandboxes think of coils of wire. You have now arrived at one of the biggest problems that radio frequency engineers face when designing circuits for radio receivers, namely the large area consumption of coils.

Just like when a sound wave is reflected against a wall and leads to an echo in an empty room, electromagnetic waves can also be reflected when entering a radio receiver. This can be avoided by performing what is called an impedance match, and this is where coils come into the design. Impedance is a generalization of resistance which, unsurprisingly, means resistance to current flow. A proper match means that the receiver has the same resistance as the antenna that feeds it. Coils have commonly been used to make sure that this condition is met and that no signal of interest is reflected, but also to limit the usable frequency range of the receiver. As previously mentioned, coils are bulky and highly impractical in modern cellphones, where a small size is of paramount importance. A very large range of frequencies are also used today, and the receivers need to be flexible, which coils directly prevent.

A number of different ways of providing the impedance match without coils have been invented and my thesis focuses on a certain type of receiver that utilizes feedback. This means that a small part of the output signal is subtracted from the input and, simply put, adjusts the signal for errors introduced by the receiver. Feedback can be described as the duct tape of analog electronics because it has almost an infinity of different uses but the interesting one for this work is its ability to make resistance look smaller than it actually is. By careful tuning of the receiver it is possible to achieve an almost perfect matching with one caveat. It takes the signal less than a billionth of a second to move through the receiver, but that is enough to make the signal arrive late. When the signal is fed back it is correcting the errors that the signal had before instead of what it currently has. Matching might still be intact but at a slightly different frequency than intended, and in some cases it drastically reduces the performance of the circuit. I have developed a system that compares a few past signals to produce an estimate of what the signal looks like in the future which re-enables perfect matching.

Noise is of utmost importance to a radio receiver. When a signal from a base station reaches a cellphone it typically is a trillion times weaker than a low-energy lamp which is comparable to the power of random vibrations of the molecules in the receiver. If great care is not taken when designing the receiver it can add a significant amount of noise and completely drown the signal. An effect known as noise-folding is particularly nasty and can add several copies of the noise to the signal. The bulk of my work is comparing various ways of combining a technique that eliminates this effect and the previously mentioned impedance matching technique. The best system tested boasts 40% better noise performance than a standard case while not increasing the power consumption by more than 10%.

The techniques used in the thesis show great promise and might see widespread use in cellphone radio receivers in the future.