FPGAs for Better Beamforming Performance

As signal processing in radar and wireless communications systems has shifted from analog to digital, great effort has gone into the development of advanced beamforming techniques to enable new applications. The ability to precisely guide beams using digital methods, the most common being Fast Fourier Transform, has resulted in significant changes in how and radar and mobile telecommunications systems are designed.

Beamforming can be switched or adaptive. In switched beamforming, a mobile telecommunications base station, for instance, chooses from a predefined selection of beams that each target a specific direction based on the strength of the received signal. As a user moves in relation to the array of antennas, the signal is switched to other elements in the array that are better positioned to provide a stronger signal in a particular direction. Adaptive beamforming, on the other hand, relies on real-time computations that allow the base station to transmit more focused beams in the direction of target users while reducing output in other directions to greatly reduce interference between elements.

Adaptive beamforming designs call for very high processing bandwidth – billions of multiply and accumulate operations must be performed each second. It therefore becomes more important for receiving systems to suppress noise sources and interference. Meanwhile, real-time directional control of each element in the antenna array must be maintained. To accomplish this, it is necessary to digitally process the signal received by each antenna element individually and simultaneously using element-level processing. Because of the heavy computational load required, traditional CPUs and digital signal processors (DSPs) can be rapidly overburdened in adaptive beamforming applications. Much higher performance FPGAs, however, are well-suited for the task due to their embedded DSP blocks, parallel processing architecture, and enhanced memory capabilities.

The ever-growing global demand for mobile broadband data and voice services continually drives wireless network operators to expand and upgrade their networks in order to deliver more capacity. Operators are simultaneously trying to maximize the number of users that each wireless base station can support to lower their infrastructure costs while maintaining an attractive price point for subscribers.

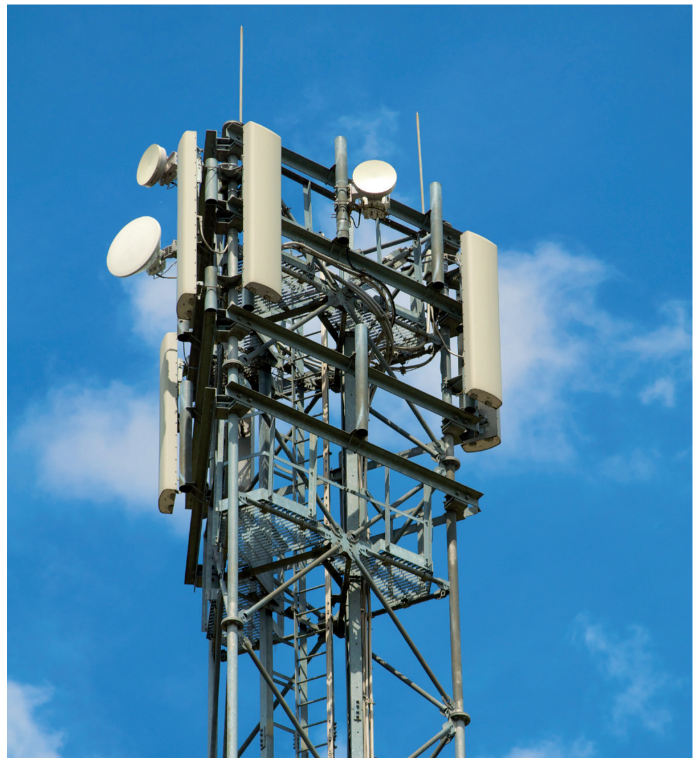

Figure 1: Cellular Array *Photo by Gareth Ellner*

This effort is complicated by the fact that the amount of available wireless spectrum is limited, so increased traffic generates more interference and call quality suffers partly because of the limitations of antenna technology. Omnidirectional antennas have been commonly used to transmit and receive on cellular towers. However, this traditional method, in which the antennas act as transducers, converting electromagnetic energy into electrical energy, is not efficient and suffers from a high degree of interference that diminishes overall connectivity due to the multiplicity of signals present at a single tower.

This interference can be mitigated through the use of directional sector antennas grouped together on the same tower. These adaptive array antennas, or smart antennas, have been increasingly used in telecommunications networks to improve wireless connection quality and boost overall capacity. This is achieved with beamforming techniques that direct beams from the base station at individual users through the use of advanced digital signal processing. Beamforming adjusts the power and phase of every incoming and outgoing signal to create a beam that travels in a specific direction while decreasing non-essential output. This reduces the amount of interference that individual signals inflict upon one another and increases the quality of all connections. The emergence of innovative adaptive beamforming algorithms has led to an increase in the use of floating-point arithmetic in signal processing to minimize interference and boosted radar capacity by enabling real-time tracking of targets. This is achieved by creating multiple spot beams simultaneously using algorithms such as QR decomposition (QRD) and weight back substitution (WBS). These algorithms facilitate the adaptive formation of beams while reducing noise and interference, but they require a large number of floating point operations per second.

Because of the size, weight, and power limitations of many radar systems, the use of legacy CPU or GPU options is not the best approach because of the increased amount of hardware required to perform the floating point calculations. The use of multiple CPUs has a major impact on the design of a radar system due to the need for more memory, power, and space, not to mention the higher cost, more complex system design, and extended integration time. A CPU-based design is further constrained by a limited choice of memory and interface options.

FPGAs offer an enormous advantage over CPU and GPU options in radar systems that employ advanced digital beamforming techniques because they can reduce, cost, complexity, power consumption, and time to market. Because of their superior ability to process highly-parallel floating point operations in adaptive beamforming applications, FPGAs can increase algorithmic performance while dramatically reducing power consumption.
An FPGA is also a much more efficient choice because a single device is used to receive and process large amounts of data over such I/O standards as PCIe and Serial RapidIO from signals captured by each element in an antenna array. In addition to providing higher performance processing, such a system eliminates the need for numerous, power-hungry, multi-core CPU boards housed in a VPX chassis requiring more than 1000 watts of power. A streamlined, single-FPGA design also benefits from external memory and other additional functions present on a single board that draws less than 80 watts.

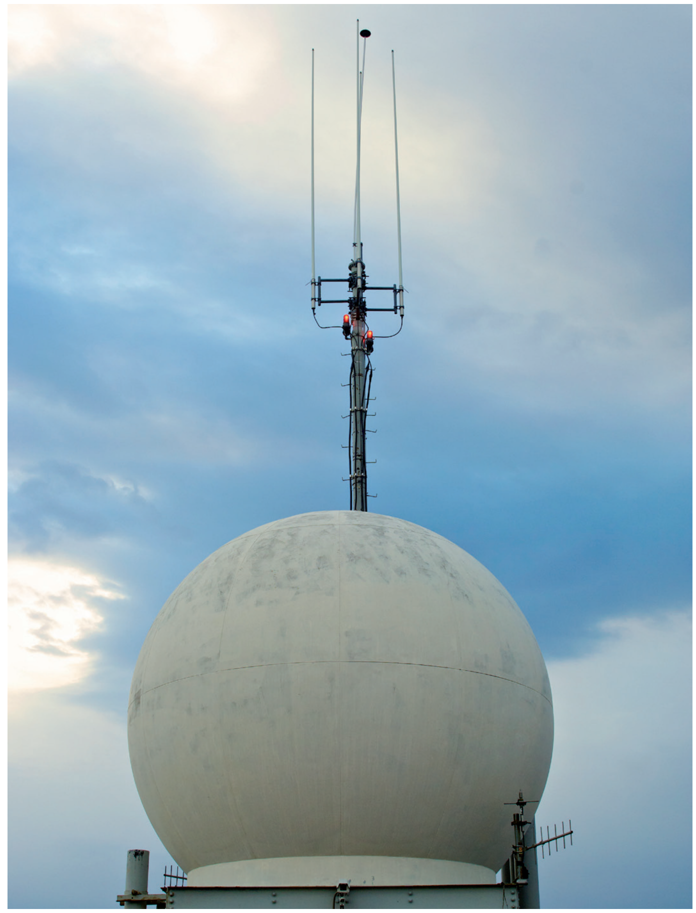

Figure 2: Radar Antenna

The use of smart antennas and adaptive beamforming, while common in military and defense applications for decades, was not extensive in commercial cellular networks until relatively recently due to the prohibitively high cost associated with widespread deployment. With the rise of low-cost FPGAs and DSPs, adaptive beamforming made its way into 3G mobile infrastructure in the early 2000's, and the technique is now widely used in expanding 4G networks. The use of high-performance analog transceivers that are tightly coupled with FPGA cards such as 4DSP's Xilinx Virtex-7-based FM788 opens up new opportunities for hardware and firmware designers to refine beamforming methods for use in both commercial and defense applications.