

Advanced Technologies Pave the Way for New Phased Array Radar Architectures

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Introduction

A large proliferation of digital beamforming phased array technology has emerged in recent years. The technology has been spawned by both military and commercial applications, along with the rapid advancements in RF integration at the component level.

Although there is a lot of discussion of massive MIMO and automotive radar, it should not be forgotten that most of the recent radar development and beamforming R&D has been in the defense industry, and it is now being adapted for commercial applications. While phased array and beamforming moved from R&D efforts to reality in the 2000s, a new wave of defense focused arrays are now expected, enabled by industrial technology offering solutions that were previously cost prohibitive.

A generic beamforming phased array signal flow is shown in Figure 2. The number of elements is chosen at the system architect level, based on aperture size, power, and antenna pattern requirements. Front-end modules are behind each antenna element.



Figure 1. Phased array system examples.

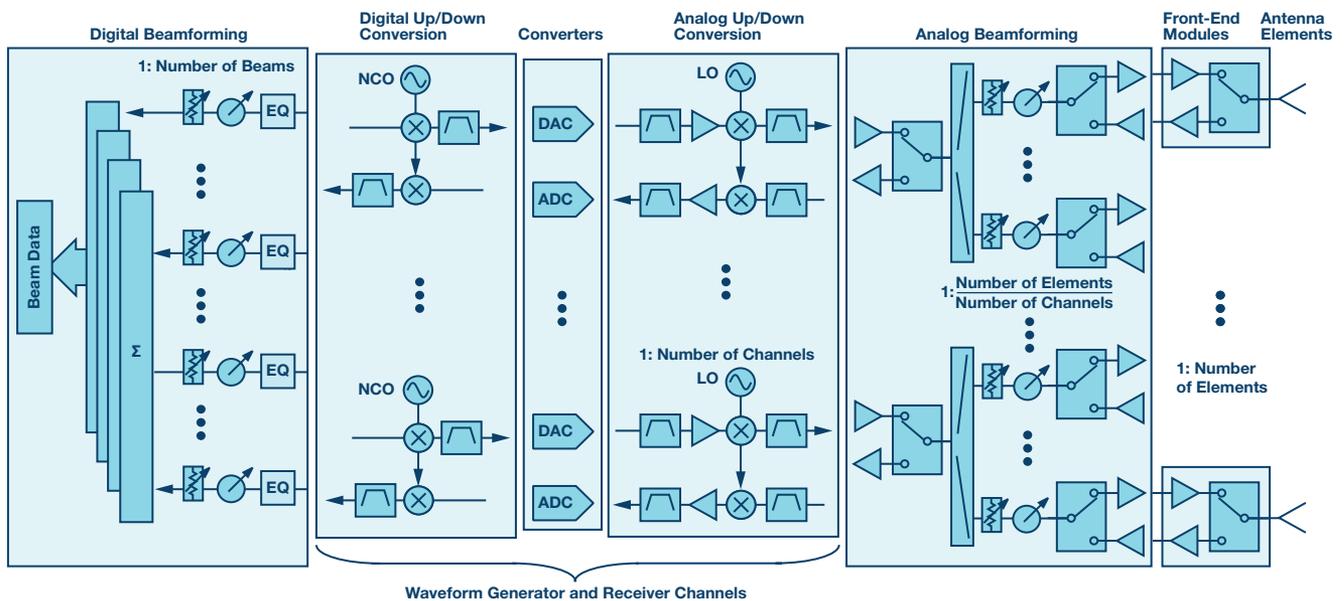


Figure 2. Generic beamforming phased array signal flow.

An analog beamforming layer is behind the front-end modules. In classical phased arrays, the analog beamforming subsystem combines all the elements to centralized receiver channels. An every element digital beamforming phased array has waveform generators and receivers behind every front-end module, and the analog beamforming layer is eliminated. In many systems today, some level of analog beamforming is common. The waveform generator and receiver channels serve to convert digital data to the operating band RF frequencies. Digital beamforming is accomplished by first equalizing the channels, then applying phase shifts and amplitude weights to the ADC data, followed by a summation of the ADC data across the array. Many beams can be formed simultaneously, limited only by digital processing capability.

Analog Devices has solutions for every section of a beamforming system illustrated, and for both analog and digital beamforming architectures.

Analog vs. Digital Beamforming Challenges

The objective of a digital beamforming phased array is the simultaneous generation of many antenna patterns for a single set of receiver data. Figure 3 shows the antenna patterns at an element, the combined elements in a subarray, and the beamformed data at the antenna level.

The primary obstacle of the subarrayed approach is that beamformed data must be within the pattern of the subarray. With a single subarray, simultaneous patterns cannot be generated at widely different angles. It would be desirable to eliminate the analog beamformer and produce an every element digital beamforming system and with today's technology, this is now possible at L- and S-band. At higher frequencies, size and power constraints often necessitate some level of analog beamforming. However, the quest remains to approach near elemental digital beamforming, which places significant demands on the waveform generators and receivers.

While the beamforming challenges place demands on the waveform generators and receivers to reduce size and power, there is a simultaneous demand to increase bandwidth for most system applications. These objectives work against each other, as increased bandwidth typically requires additional current and additional circuit complexity.

Digital beamforming relies on the coherent addition of the distributed waveform generator and receiver channels. This places additional challenges on both synchronization of the many channels and system allocations of noise contributions.

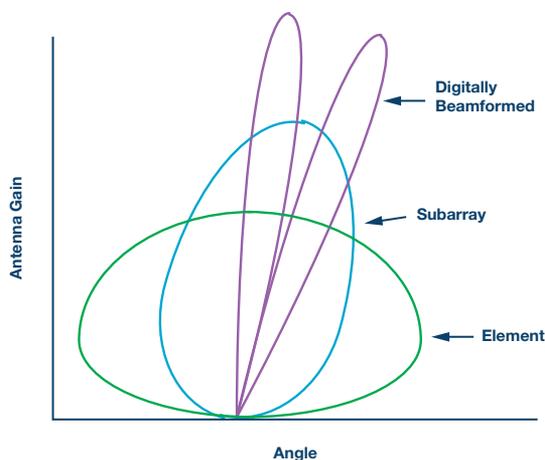


Figure 3: Digital beamforming antenna pattern.

RF Signal Chains

Table 1 shows some of the most common receiver architectures in use today. The superheterodyne, direct sampling, and direct conversion architectures form the basis of most RF systems. Although only the receiver is shown, the topologies also apply to the waveform generator signal chains.

Table 1. Receiver Architecture Options

Configuration	Benefits	Challenges
<p>Heterodyne</p>	<ul style="list-style-type: none"> ▶ Proven and trusted ▶ High performance ▶ Optimum spurious ▶ High dynamic range ▶ EMI immunity 	<ul style="list-style-type: none"> ▶ SWaP ▶ Many filters
<p>Direct Sampling</p>	<ul style="list-style-type: none"> ▶ No mixing ▶ Practical at L/S band 	<ul style="list-style-type: none"> ▶ Analog-to-digital input bandwidth ▶ Gain not distributed across frequency
<p>Direct Conversion</p>	<ul style="list-style-type: none"> ▶ Maximum ADC bandwidth ▶ Simplest wideband option 	<ul style="list-style-type: none"> ▶ Image rejection ▶ I/Q balance ▶ In-band IF harmonics ▶ LO radiation ▶ EMI immunity (IP2) ▶ DC and 1/f noise

The superheterodyne approach, which has been around for a hundred years now, is well proven and provides exceptional performance. Unfortunately, it is also the most complicated. It typically requires the most power and the largest physical footprint relative to the available bandwidth, and frequency planning can be quite challenging at large fractional bandwidths.

The direct sampling approach has long been sought after, the obstacles being operating the converters at speeds commensurate with direct RF sampling and achieving large input bandwidth.

Today, converters are available for direct sampling in higher Nyquist bands at both L- and S-band. In addition, advances are continuing with C-band sampling soon to be practical, and X-band sampling to follow.

Direct conversion architectures provide the most efficient use of the data converter bandwidth. The data converters operate in the first Nyquist, where performance is optimum and low-pass filtering is easier. The two data converters work together sampling I/Q signals, thus increasing the user bandwidth without the challenges of interleaving. The dominant challenge that has plagued the direct conversion architecture for years has been to maintain I/Q balance for acceptable levels of image rejection, LO leakage, and dc offsets. In recent years, the advanced integration of the entire direct conversion signal chain, combined with digital calibrations, has overcome these challenges, and the direct conversion architecture

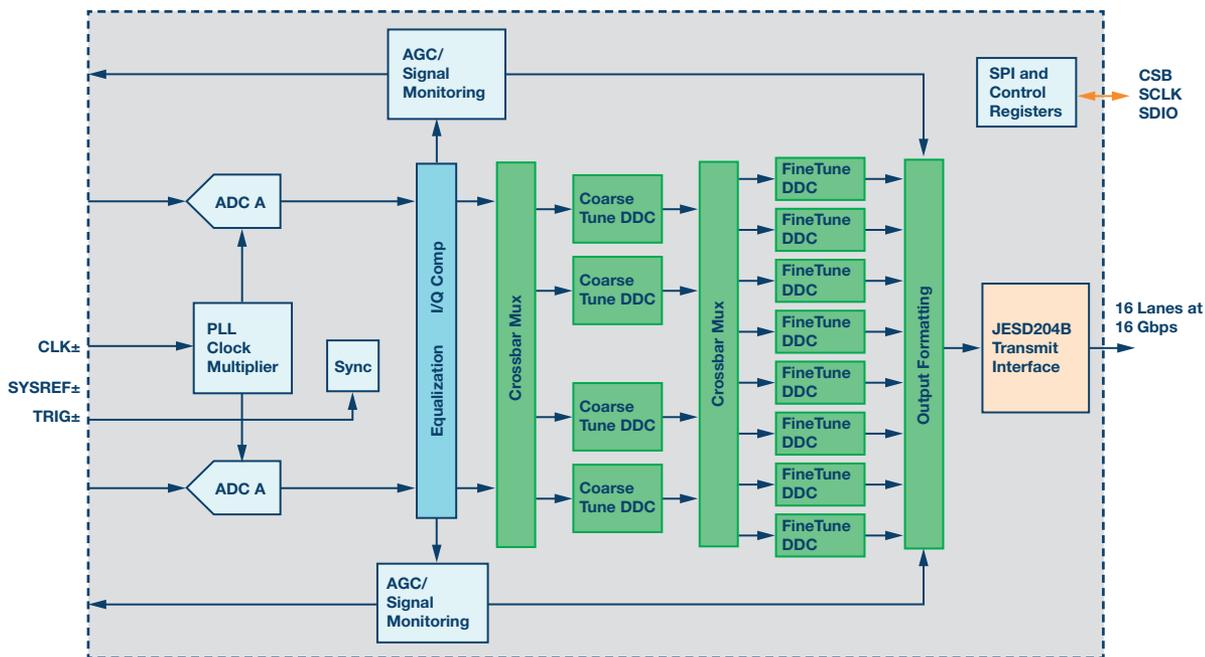


Figure 4. Embedded digital features offload FPGA processing.

is well positioned to be a very practical approach in many systems. Here at Analog Devices, we are continually advancing the technology for all the signal chain options described. The future will bring increased bandwidth and lower power, while maintaining high levels of performance, and integrating complete signal chains in system on chips (SoC), or system in packages (SiP) solutions.

Data Converter Digital Assistance

Data converter analog performance will continue to improve and these improvements at the analog level will include increased sampling rates for wider bandwidth, increased channel count, and maintaining the key performance metrics of noise, density, and linearity. These benefits will drive all of the RF signal chain solutions described, aiding new phased array solutions.

An area of increased importance at the system level is the recent addition of many digital functions (as shown in Figure 4) that can be used to offload FPGA processing and help the overall system. Recently released data converters include digital downconversion and filtering, which potentially reduces the data rate to the FPGA, reducing system power and FPGA processing requirements. Emerging Analog Devices data converters will continue to add functionality, such as equalization and features at the front end of the digital beamforming processing.

Analog Beamforming

At high frequencies or for low power systems, an every element system is challenged by size and power requirements. The use of analog beamforming reduces the number of waveform generator and receiver channels required to be digitized.

Analog beamforming of phased array antennae is accomplished by adjusting the phase of the signal in individual elements to steer the direction of the radiation pattern or beam. Figure 5a shows a generic analog beamforming example. Phase shifters are provided on both transmit/receive for beam steering, and many elements are combined to a single output. Figure 5b shows a functionally equivalent example where the phase shifter and attenuator are common to both the transmitter and receiver path enabled by microwave switches. The later topology reduces the number

of phase shifters and attenuators required, but may require more frequent command updates to the devices.

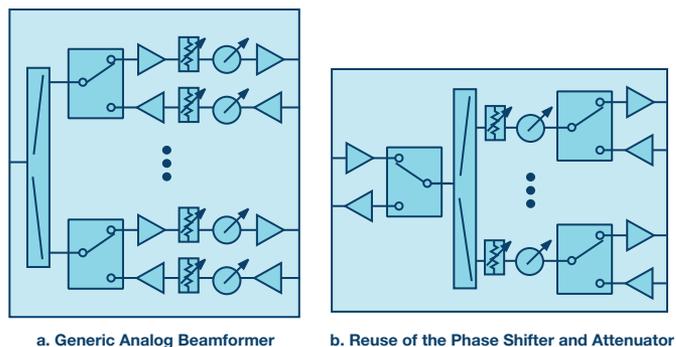


Figure 5. Analog beamforming.

To overcome the constraints of a single subarray, multiple subarrays can be produced with a topology, such as shown in Figure 6.

In this topology the low noise amplifier (LNA) outputs are split to many analog beamformers where N number of elements can produce M number of analog subarray beams. Each analog beamformer is programmed for a different antenna pattern. By repeating the Figure 6 topology across an array, digitally beamformed patterns can be created at widely disparate angles. This topology is one type of hybrid architecture that can provide the benefits of every element digital system, but with a reduced waveform generator and receiver count. The trade-off in this case is the analog beamformer complexity.

Traditional analog beamformers would have required a single function GaAs phase shifter and single function GaAs attenuator for each antenna element. More advanced approaches integrate the phase shifter and attenuator into a single GaAs front-end IC, that includes the power amplifier (PA), LNA, and switch. Analog Devices integrated analog beamformer chips achieve significant integration in SiGe BiCMOS technology, that incorporate four channels into a single IC with a reduced footprint, and less power dissipation.

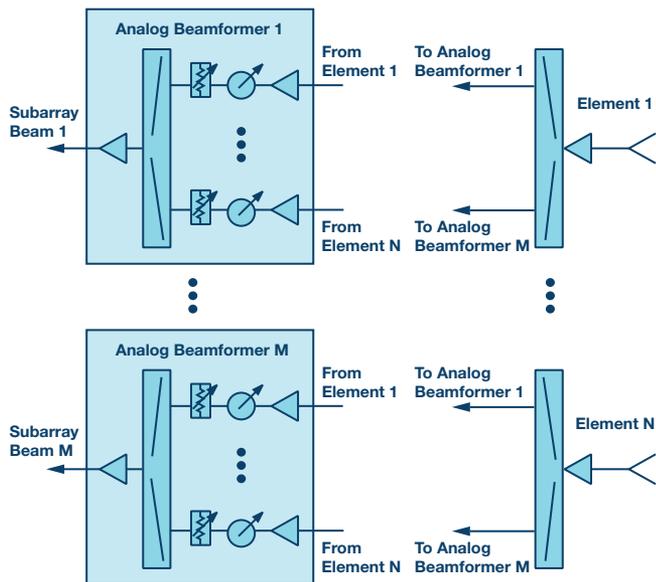


Figure 6. A multi-subarrayed analog beamforming architecture.

Front-End Modules

The front-end modules, sometimes called transmit/receive (T/R) modules, provide the interface to the antenna element. The front-end module is critical in terms of transmit power and efficiency, as well as receiver noise. The high power amplifiers (HPA) set the output power. The LNA establishes the system noise performance. Many systems require provisions for calibration or additional filters, and an example front-end module block diagram is shown in Figure 7.

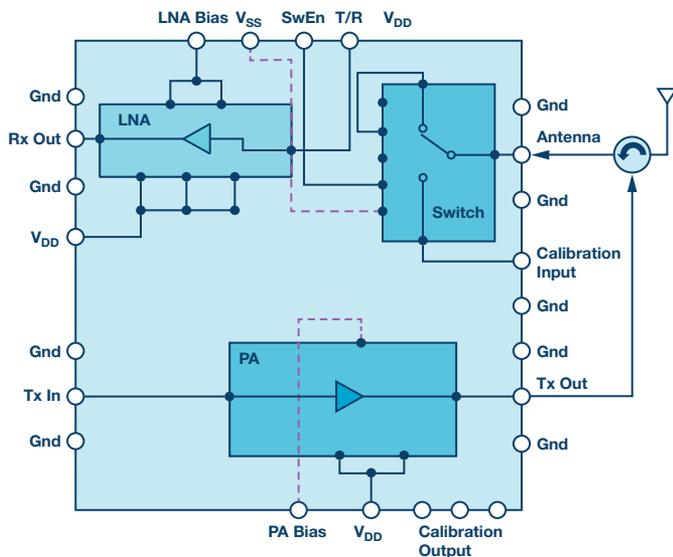


Figure 7. Example front-end module block diagram.

Summary

Digital beamforming phased arrays are now common, and rapid proliferation is expected with a huge range of frequencies and architectures being developed from L-band through to W-band.

Analog Devices is enabling new system developments with SiGe beamformers, microwave frequency conversion, front-end modules, and high speed converters. Our beamforming solutions combined with our power amplifiers, low noise amplifiers, and switch technology enable Analog Devices to be the only antenna-to-bits supplier in the market, offering optimized solutions to our customers' complex system problems at both the semiconductor and integrated subsystem level.

About the Author

Peter Delos is a technical lead at Analog Devices, in the Aerospace and Defense Group. He received his B.S.E.E. from Virginia Tech in 1990 and M.S.E.E. from NJIT in 2004.

He worked in the Naval Nuclear Power Program from 1990 to 1997. This work included completion of the Naval Nuclear Power School Officer's Program, work as an instructor in a naval submarine facility, and lead electrical field engineer work on the Seawolf class submarines in Groton, CT.

In 1997, he accepted a position with Lockheed Martin in Moorestown, NJ, and began a prolific career developing receivers/excitors and synthesizers for multiple radar and EW programs. This experience encompassed architecture definition, detailed design, rapid prototypes, manufacturing coverage, field installations, and coordination among many engineering disciplines. This work led the migration of phased array receiver/exciter electronics from centralized architectures to on array digital beamforming systems.

In 2016, he accepted a position with Analog Devices in Greensboro, NC. He has nearly 20 years of experience in RF systems designing at the architecture level, PWB level, and IC level.

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