Microwaves&RF

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The Basics of Radar Technology (Part 2)

Explore radar's development trajectory and how the shift to element-level digital phased arrays is spurring trends that impact component selections.

In Part 1 of this series, we covered some basic radar functions and design parameters, the factors driving gain in search radar systems, and various approaches to increasing radar performance. Part 2 covers the top trends we're observing as we shift to element-level digital phased arrays and how these trends are impacting component selection.

The Phased-Array Evolution

Radar systems function in defense communication, space exploration, remote sensing, law enforcement, air traffic control, and many other applications where they're operationally critical. With growing demand for multifunctional systems, we're asking more and more of radar technologies.

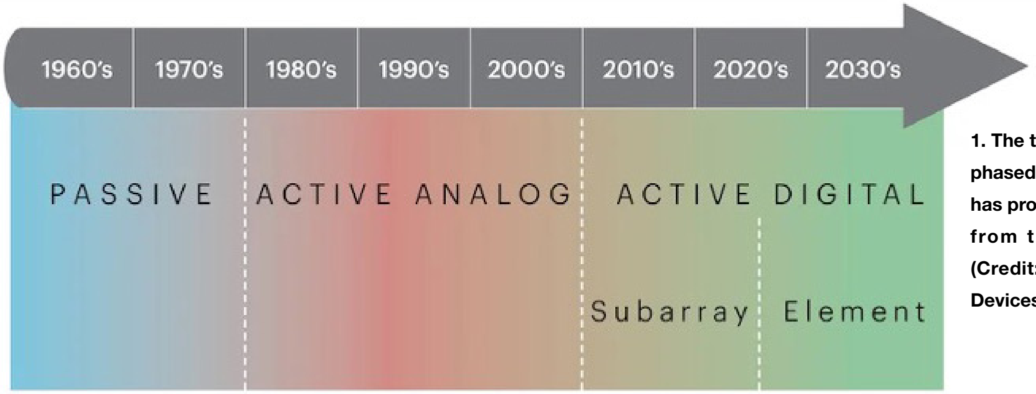
In the context of defense-related applications, the evolution of phased-array antennas has progressed from passive phased arrays to element-level digital phased arrays over the last half-century *(Fig. 1)*. We're already reaping the benefits of the shift.

Many radar systems currently in use are based on previous generations, but today's element-level digital arrays have more flexibility in terms of mode and bandwidth. Further, since each element in the array has its own analog-to-digital converter (ADC), there's an inherent increase in signal-to-noise ratio (SNR). Systems being designed today will make even better use of these benefits.

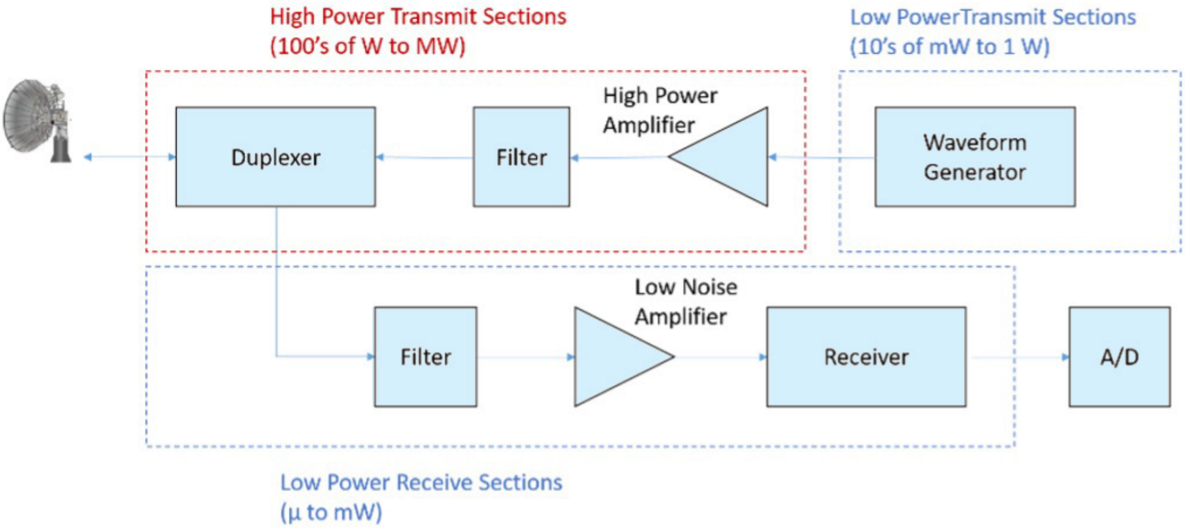
The Core Functional Blocks in Radar Systems

As mentioned in Part 1, one way of understanding radar design is to think of the system as a combination of functional blocks that perform key roles *(Fig. 2)*:

- **Common circuit-card assemblies:** Circuit assemblies are responsible for implanting the functions shown in *Figure 2*. Modern common circuit-card assemblies (CCAs) are highly integrated and compact, which accommodates more electronics on a smaller card. There are two common options: digital receiver/exciter CCAs and transmit/receive module CCAs.•**Digital receiver/exciter (DREX):** DREX is a CCA in modern radar systems, leveraged by both hybrid and fully digital beamforming arrays. The transit path includes a digital exciter with an integrated waveform generator, a digital-to-analog converter (DAC), and a frequency synthesizer. The receive side has a digital receiver, an analog-to-digital converter (ADC), and a frequency synthesizer. While there's typically an up/downconversion step, some systems can go direct to digital, and more systems will be expected to do so soon.
- **Transmit/receive (T/R) module:** T/R modules, primarily used in radar systems, are designed to handle both the transmission and reception of radio signals through



1. The technical evolution of phased-array radar systems has progressed significantly from the 1960s onward. (Credit: Knowles Precision Devices)



2. Radar systems feature functional blocks that perform key roles. (Credit: Knowles Precision Devices)

the same antenna by rapidly switching between modes. Radar systems emit pulses and then "listen" for echoes to determine characteristics of the target, including range and speed. Many T/R modules are designed and manufactured in-house on a common development platform because their construction depends greatly on the team's approach to packaging and integration.

Advancing Capabilities of Phased-Array Radar

Today, and looking forward, two key trends are driving advances in radar systems: digital architectures and heterogeneous integration. Innovation, enabled by these trends, continues to enhance performance, increase flexibility, and improve system integration.

Digital architectures

Advances in radar reflect the need to process more data about the battlespace as quickly as possible and often from the field. Operating mostly in the digital domain enables this to happen with minimal cost and complication.

Digital-array radar is built on phased-array antenna fundamentals. In this new era, transmitted and received energy can be digitized at the element level, so digital-array radar can simultaneously form multiple receive beams. There are only a few limitations to the number of beams, instantaneous bandwidth, and dynamic range: data converters, digital hardware specifications, and power consumption. As advances emerge in these areas, digital arrays are relevant for applications with higher and higher operating frequencies.

In digital microwave, modern ADCs and better digital-signal-processing (DSP) capabilities facilitated the shift from superheterodyne to direct sampling, changing the role of the filter to focus on processing in the digital domain and reducing the need for multiple analog stages. As the bandwidth and sampling frequency of RF-ADCs expands, every-element digital receiver/exciter (DREX) modules are becoming more common, too. DREX modules combine ADCs and DSP to perform direct sampling on RF signals at higher frequencies. Without the signal degradation and latency associated with downconversion, the upper frequency limit increases for direct sampling.

To access the potential benefits of integrated devices in a digital-at-every-element approach, all components need to fit within an array pitch, often considered half of the free-space wavelength ($\lambda/2$) of the radiation. In other words, for the X-band, this is 12.5 mm (just under half an inch). In principle, every function from the T/R module through DREX needs to fit into a rectangular cuboid that would measure at most $\lambda/2$ square in the axes parallel to the face of the array.

Heterogeneous integration

As mentioned above, digital architectures have created more demand for small, well-integrated components. Heterogeneous integration (HI) enables several radar functions to combine in one compact, high-performance device.

While this trend is a result of the growing interest in digital architectures, it's inspired a new approach to building these systems, where fewer components are available to purchase and integrate. Examples of this idea exist today—consider the DREX modules mentioned above, synthesizer modules, and T/R modules of the world.

For these integrated devices to be most functional in radar applications, they need to meet certain criteria. For instance, they need to be easily customizable. This becomes possible with the necessary supporting components, namely a tightly integrated semiconductor.

Today, CCAs are still considered large and expensive compared to the promise of an integrated package that contains all relevant components for an antenna element. Given the amalgamation of demands, we expect to see further interest in HI approaches to building systems.

Heterogeneous Integration in RF and Microwave Design

Integrated passive devices (IPDs), like capacitors, conductors, and resistors, are largely responsible for the performance optimizations that result when components combine in HI. In other words, HI-based designs rely on the performance and manufacturing optimization of IPDs. As these components become more and more advanced, here are a few changes you can expect:

- **Performance improvements:** Changes to the bill of materials (BOM) and underlying technologies can have larger impacts on performance. For example, in radar applications, amplifiers and oscillators are more efficient when designed with materials like gallium arsenide (GaAs), gallium nitride (GaN), and silicon (Si). IPDs offer lower parasitic effects, tighter tolerances, and more consistent temperatures than discrete components. Some are specially designed to improve EMI performance in dense electronics.
- **Higher functional density:** By design, HI increases functional density. The result is smaller and lighter devices, and with a mix of digital and analog components, engineers have the support and capacity they need to create more complex systems.
- **Lower costs:** Minimizing the number of separate components and assembly steps can reduce overall costs. IPDs integrate components for a simpler design process, which translates to a simpler BOM and a less involved manufacturing strategy. This combination reduces time-to-market and production costs.
- **Higher reliability:** Reducing the number of interconnects and solder joints in a design reduces failure points. With fewer failure points and fewer discrete components, IPDs can be designed with robust materials that can stand up to harsh operating environments over time.

Raising the Bar for Electronic Components in Radar Applications

Radar systems are being asked to do more with less—a smaller footprint in terms of size, weight, power, and cost (SWaP-c), so the defense industry is looking toward small, multifunctional devices that can manage in the digital domain. As a result, there's a new set of standards for those supplying components for radar systems.

Component manufacturers need to:

- Design to fit within λ/2.
- Focus on high Q and low loss.
- Plan for seamless integration with other parts and functions of the assembly.

As radar systems evolve to meet modern demands, the value of low-loss, high-efficiency components can't be overstated. With the shift toward element-level digital phased arrays, enhanced by HI, it's imperative that IPDs can support them with high reliability and efficiency. Optimizing SWaP-c will remain an important aspect of delivering radar systems that are capable of unprecedented precision and efficiency in challenging scenarios.