# Trends in Wideband Phased-Array Front-Ends

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*Abstract*— **Wideband phased-array front-end technology is characterised by stringent specifications, increasing cost-pressure and is subject to fundamental changes. This paper addresses trends observed for these systems, both in relation to the functionality required (including the architecture of the system and the platforms upon which they are applied) as well as in relation to the technologies that may be employed.**

## I. Introduction

Phased-arrays are widely used in the military and space domain, and are more and more often also encountered in the telecommunication community. They offer great advantages in terms of performance, mode of degradation and flexibility. The advantages related to the performance and flexibility are most obvious when comparing rotating systems with phased-arrays. Due to the phased-array nature, switching between different antenna beams can be almost instantaneous. The system can therefore perform more, or more demanding, functions and multifunction systems become feasible. The advantages due to the mode of degradation are easily summarised with the observation that fewer individual components can lead to a full failure of the system.

The price to be paid for all these advantages is the complexity of a phased-array. Speaking for the front-end, every individual antenna element needs its own T/R module, including several different functions such as low-noise amplification, power amplification, phase shifting and often amplitude control. It hence takes a large effort to control (and control the cost of) these systems. The absolute phase relations between the different modules must be guaranteed, over time and operating conditions, and calibration is an art in itself.

This paper will limit itself to five trends observed that have direct impact on the front-end. Issues such as software, processing and infrastructure will not be discussed.

## II. Trends observed

**Trend one: Smaller systems.**

Traditionally, phased-arrays were present only for the largest of radar systems. The gigantic ballistic missile early warning systems speak for themselves in this matter. The development costs were huge, and also the physical size of the systems was large to say the least. For a wider proliferation of phased-arrays, or active electronically steered arrays (AESA's), smaller systems were needed. Naval and air- or spaceborne systems put requirements on maximum size and power dissipation and smaller systems were the result.

Under pressure of decreasing defence budgets, the number of large phased-array systems that are under development is relatively limited. Initiatives for smaller systems, on the other hand, seem to be ever increasing. All the major radar integrators are working on small radar systems to be mounted at Unmanned Aerial Vehicles (UAV's), and several radar houses, but also smaller companies, now have phased-arrays available for commercial applications. As a consequence, the emphasis is more put on 'what the technology can cheaply offer', as compared to the breakdown of system specifications into the module requirements, regardless of the cost.

**Trend two: Integration technology.**

The front-end is a relatively costly part of the AESA due to the intrinsic cost for an individual module, combined with the fact that a large amount of front-ens is needed per system. Hence, a strong focus on the front-end components is present. Two important cost drivers for the front-end are the semiconductors and the packaging.

In the first place, the number of semiconductors will be limited as much as possible. By doing so, the modules will be simpler and hence cheaper. A minimum of two monolithic microwave integrated circuits (MMIC's) per transmit-receive module is likely to remain, as long as power levels above several Watt per module are required: one power amplifier and an IC that performs the rest of the functionality.

Packaged components will start to dominate in the front-end as well. Contrary to the bare-die approach that is seen so far, IC's packaged to ensure local hermiticity are expected to appear shortly. As a result, cheaper assembly processes and module housing will appear.

SiGe will be added to the traditional GaAs components. This may bring cost advantages but will also undoubtedly bring possibilities for enhancing functionality and may bring A/D conversion into the module. As a consequence, the architecture of the whole AESA will be reconsidered. A consolidation in the manufacturing industry combined with more restricted export policies will increase the importance of access to technology.

**Trend three: Digital beamforming.**

In forming the beams from all the individual signals obtained at the antenna element level, both on transmit and receive, the individual signals have to be added coherently. This can be performed based on the RF signal, it can be performed after down-conversion (with the IF signal), it can be performed after up-conversion in the optical domain and it can be performed on digitised signals. The particular choice is obviously very important for the architecture and cost of the front-end. As the front-end module is to be manufactured for every antenna element, it is also a very significant parameter in the system design.

The vast majority of the existing AESA's uses RF beamforming, although optical beamforming can incidentally be found for very wideband systems (e.g. a decade bandwidth), and digital beamforming can be found for some recent systems.

In virtually every electronic system, the digital portion of the system is increased as far as feasible. Processing comes almost for free and flexibility is greatly facilitated in the digital domain. As compared to digital technology, microwave beamforming is a very tedious mechanism. The precision required in all mechanical components and the electromagnetic sensitivity are challenging to say the least.

One of the challenging aspects for a wideband phased-array is the data rates that are involved when full receivers, including A/D converters, are required per antenna element. Furthermore, the radar system must generally use coherent receivers. Hence, the precision requirements that disappear from the RF beamformer re-appear in the distribution of the local oscillator signal and timing signals to the individual receivers.

The winning argument, however, is that adding more beams to a system is no longer equivalent to adding more RF beamformer hardware but is reduced to adding more software and processing power. From a manufacturing perspective, this is obviously highly attractive for reasons of re-use of architecture and implementation, for future upgrades in the system performance and to open future development paths in directions that are not yet certain.

For the receive path, the introduction of A/D converters at every antenna element is hence very advantageous, as the flexibility of the beamforming is greatly enhanced.

**Trend four: Separation of transmit and receive.**

The transmit beam is normally generated in a central waveform generator, distributed to the individual antenna elements, followed by a phase-shifting beamforming network and then amplified in power.

In analogy to the digital beamforming on receive, the equivalent for the transmitter would imply a waveform generator per antenna element, with the calibration being performed by presenting time-delays or phase-shifters in the digital domain to the individual waveform generators. For some MIMO research radar systems this set-up can indeed be found.

This equivalent does unfortunately not hold generally, as the availability of different transmit beams simultaneously is not a very common requirement, and the principal argument for digital beamforming on receive hence fails. The transmit beam, however, is often less stringent in its requirements and may not need the same level of amplitude control and calibration. Finally, the integration level of waveform generators is not of the same level as that for A/D converters and the need for wideband, high-quality waveform generators is, contrary to the need for A/D converters, not widely shared with other applications.

The easiest way forward is hence to use transmit beams that are generated centrally and that are wide enough to cover the projected receive beams. As a consequence, the architecture of the system is not identical for transmit and receive. The power and the low-noise problem may result in two different modules that do not necessarily need to be co-located, but can be optimised for the functionality needed.

Also for signal generation, the technology is rapidly moving ahead and becoming cheaper over time. It is expected that part of the hardware on transmit will also be distributed, such as more radar signal generators per antenna face, but to a lesser extend and for different reasons than for the receive function. The driving force is expected to be found in reconfigurability of parts of the system.

**Trend five: Reconfigurability.**

One of the issues upon employing AESA's is that shorter and shorter development cycles are needed. User needs may vary from mission to mission and requirements to implement e.g. new waveforms should be implemented at very short time-scales.

The development of an AESA is further a very costly matter. Only when costs can be shared among as much different systems as possible, a cost-effective system portfolio may be developed. Re-use of developments for different systems is paramount.

The only answer to these two observations can be reconfigurability. Developments on items such as antenna elements, power amplifiers, modules and system architecture must be intrinsically reconfigurable to be able to stay up-to-date and cost-effective at the same time as being capable to quickly respond to changing user needs.

## III. Conclusion

As has been the case for several decades now, the world for phased-array front-ends is rapidly changing. Both in their application, as well as in their architecture and the technology applied large changes are foreseen.

Making the right choices for all of these issues is of paramount importance for the industries involved: it is a matter of survival. Among all these changes only one thing seems to be really certain: These will not be the last changes!