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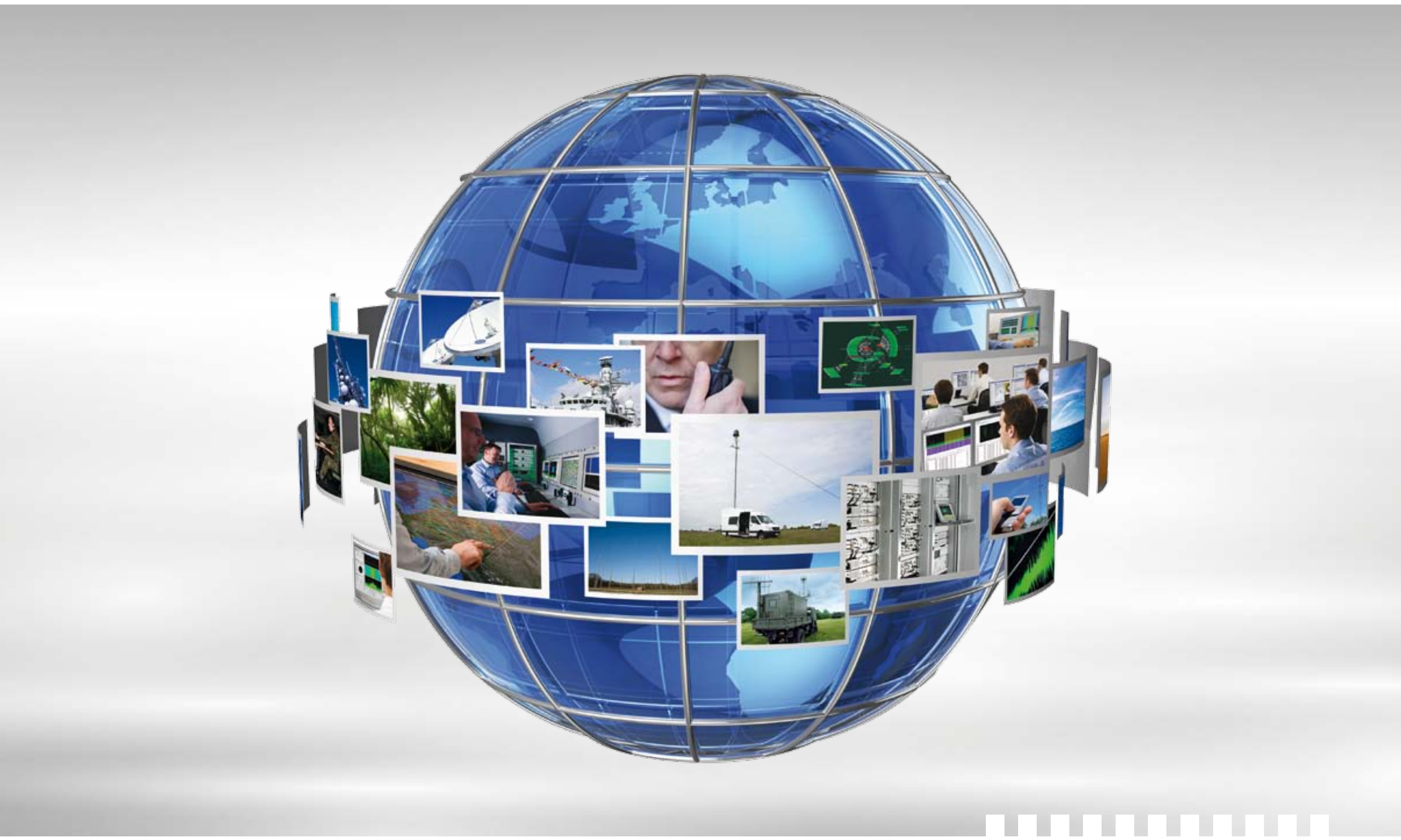

## New Signals, New Threats, New Challenges

Advanced DF Systems and Techniques Rise to Meet the Challenge

**By John Haystead**

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PLATH

# New Signals, New Thr
## Advanced DF Systems and Techni

By John Haystead

Although direction finding (DF) systems are generally thought of as intelligence-gathering tools for locating an RF emitter of some type, such as a radio or radar, in fact, accurate and high-speed DF capabilities are critical to all manner of military systems including self-protection suites, homing weapons, and real-time situational awareness tools.

To serve this myriad of applications, a number of different techniques have been developed over the years ranging from classic Watson-Watt and Doppler angle-of-arrival (AOA) techniques to time difference of arrival (TDOA), power of arrival (POA) and hybrid approaches. With further advancements in signal processing technology, more complex approaches, such as correlative/coherent interferometry, vector matching and others, have also become possible. Ultimately, however, it is the overall mission requirement, the sophistication of the signal being sought, and the physical environment in which a system is operating that determines the best technique or combination of DF techniques for the job.

### IS IT DF OR GEOLOCATION?

In the tactical operational environment, the term "geolocation" often supplants direction finding when describing the purpose and capabilities of systems. Says Martin Atanassov, Director of Marketing at Rohde & Schwarz (Munich, Germany), "Geolocation is the state-of-the-art today. Three or more advanced scanning DF receivers at different locations can automatically deliver results to a DF server which then correlates and calculates the exact position of the emitter. Even with only a short-time emission or signal, you can get a geolocation result in nearly real time."

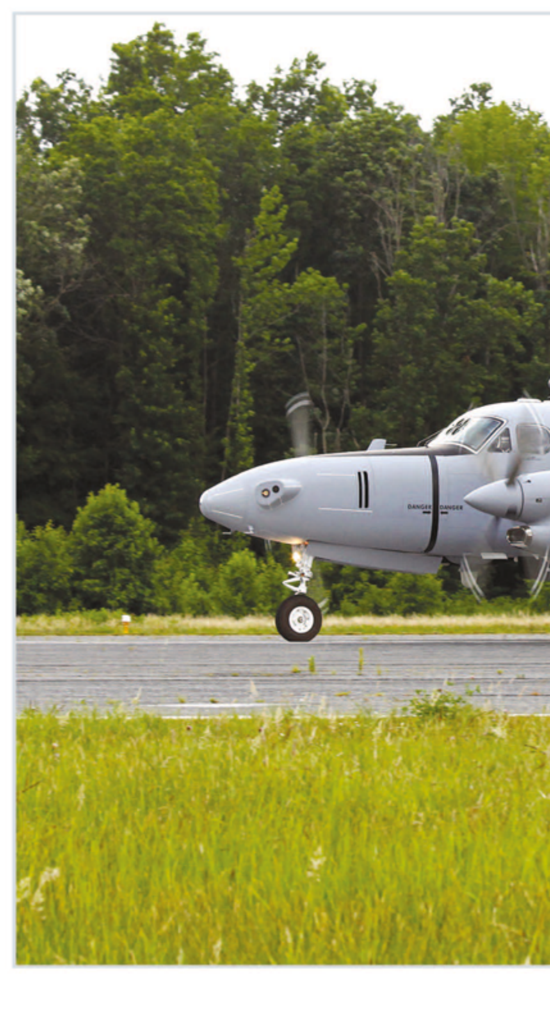
But, as pointed out by Dr. Andreas Schwolen-Backes, Chief Technology Officer, Plath (Hamburg, Germany), the distinction still depends on the requirements/mission of the user. "Sometimes these requirements can be met using multi-position location fixing, or a 'running fix', where a mobile DF system, such as an aircraft or UAV, takes multiple bearings of an emitter over a short time to determine its position. This 'DF-on-the-move' is also typically the case for a weapon system homing in on a target in the last mile without connectivity to a network. In these cases, geolocation techniques will not work, but the classic Watson-Watt AOA DF approach will."

Didier Boyet, Electronic Warfare & Radiosurveillance Business Segment Manager at Thales Communications & Security (Colombes, France), agrees, noting that other DF techniques can also allow for instantaneous geolocation, such as the simultaneous detection and determination of both the azimuth and elevation of a signal combined with a digital terrain mapping capability. "This can give you an indication of whether the emitter is on the top of a hill or at sea level, and although it will require specialized hardware and software to detect both azimuth and elevation, it may provide instantaneous geolocation without the use of an on-the-move airborne platform."

Schwolen-Backes says the distinction will ultimately still depend on the signal and mission scenario. "In the case of short-burst or low-probability-of-intercept (LPI) transmissions, it's not sufficient to monitor and DF the signals via a classical search or monitoring receiver. When you expect these types of signals in your mission, you have to ensure that each detection of an emission will lead to a DF result. This is especially important when we talk about self-protection systems, where every second counts."

On the other hand, Schwolen-Backes acknowledges that in the tactical battlefield environment, geolocation is a requirement for almost all systems, "because users are normally interested in who is doing what, when, why and where. But, for the 'where,' the DF results still have to deliver the most important input to the geolocation calculation."

Eric Vogel, SIGINT Program Director at BAE Systems (Nashua, NH), agrees that

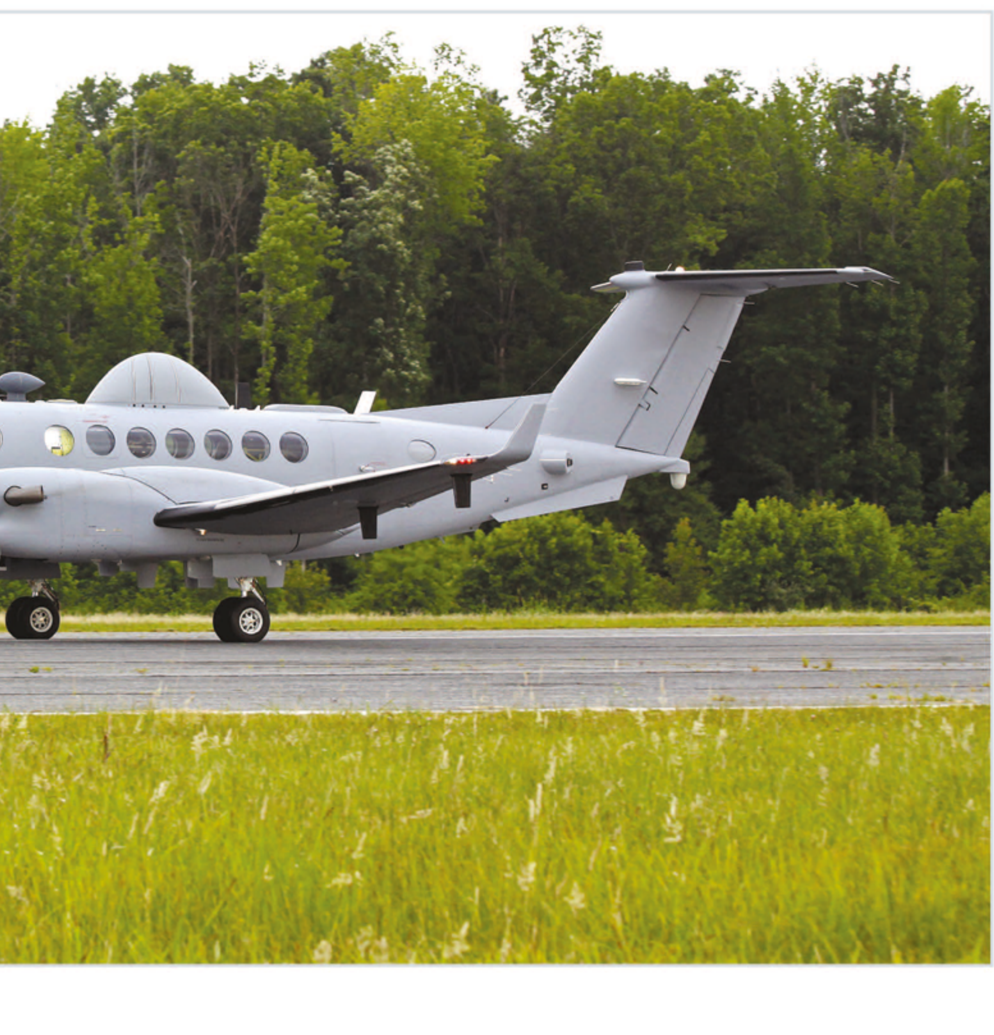


# eats, New Challenges

## ques Rise to Meet the Challenge

geolocation is the state-of-the art today. "DF and geolocation are associated together, and for tactical commanders, the key factor is time, so the problem of the day is how quickly a system can get them a high-confidence answer on a geolocation." Vogel also highlights system agility as a major requirement, "both agility in the moment to address a variety of different targets across the spectrum, as well as agility over time to be able to DF and geolocate new targets as they emerge, to keep pace with the signal environment."

Another way to consider DF and geolocation functionality and purpose is whether the primary focus is on radars (ELINT) or communication devices (COMINT). Larry Rexford, Electronic Warfare Strategic Development and Marketing Manager, Rockwell Collins (Richardson, TX) says from a strictly ELINT perspective, "basic DF is the opening argument, especially for technical collection. The key is not the precise geolocation of the emitter, but the angle-of-arrival and the ability to get high sensitivity and high gain on that signal so that you can process and exploit it for parametric data through the sidelobes and backlobes rather than through the main beam."



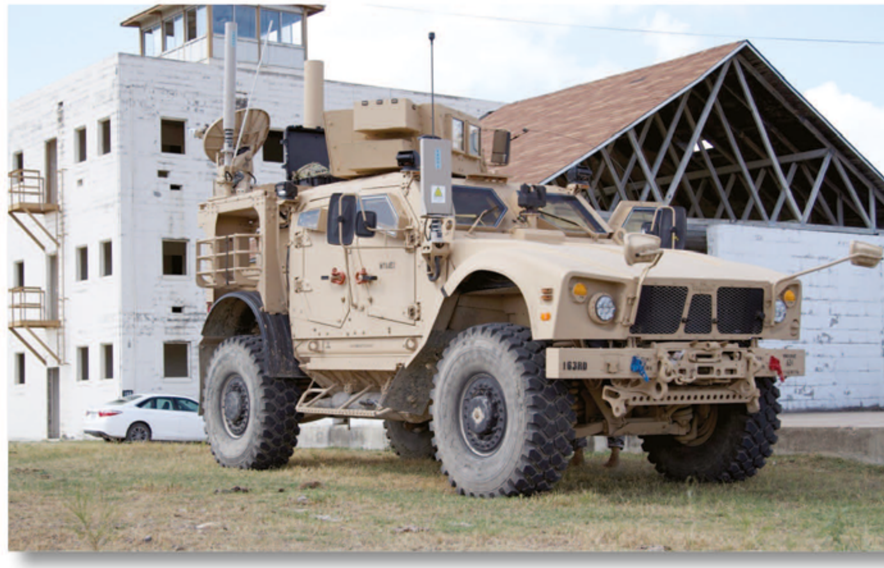
Still, Rexford agrees that in an operational environment, geolocation will be more important than the parametrics of the radar system and where real-time signal information is being used to cue other sensors in a multi-ELINT application. One of the trends he observes is "a convergence of the situational awareness mission that used to be done through electronic support measures (ESM) systems and the technical collection capabilities done through a specific SIGINT platform. In either case, DF is important."

### WHAT IS THE REQUIREMENT?

Regardless of all other factors, assured signal detection is always the first requirement for an effective DF/geolocation system or technique. Today, with the advent of spread-spectrum and frequency-agile low probability of intercept (LPI) signals, this can be an increasingly difficult and complex task.

As described by Philipp Strobel, Rohde & Schwarz Product Manager for Direction Finders and Receivers, "the typical hopping speed of frequency-agile emitters is in the range of 500 hops per second, but today there are systems coming out with up to 2,000 hops per second. Commercial standards, like Bluetooth, already operate at 1,600 hops per second, for example. These hopping rates can be a challenge for radiolocation systems." The bigger challenge, however, adds Rohde & Schwarz's Atanassov, comes from spread-spectrum signals, which can hide beneath the noise floor in the spectrum. "Since you may not even see these signals, you won't even see a need to take action." To deal with these advanced signals, Atanassov says systems require higher instantaneous bandwidth as well as high-speed scanning capability. "The combination is the key factor in increasing the probability of intercept."

Plath's Schwolen-Backes agrees. "You have to ensure that the DF system has both very good time resolution and very high scanning speed, and sometimes this means a bit of a tradeoff with frequency resolution. But, you nonetheless have to ensure both adequate frequency and time resolution to measure the signal correctly, and you also have to ensure that the bandwidth of the system is wide enough and the scanning speed fast enough. You have to match the right numbers to the different scenarios."



## AN EVOLUTION OF TECHNIQUES

Assuming the signal-detection challenge has been met, the real job of a DF or geolocation system begins. And, this is by no means a simple task, with a number of established and new techniques being employed. These techniques are largely developed for, and intimately linked to, the requirements of specific applications.

In addition to the classical Watson-Watt interferometer AOA approach to DF which uses Adcock (or crossed loop) antennas to compare the amplitude of the signal received at each antenna and computes its bearing based on the differences between them, time-difference-of-arrival (TDOA) geolocation techniques are also in increasingly common use. With conventional TDOA, a signal is received at three or more networked receivers sited at different locations and, because the signal paths will be of different length, the differences in their time of arrival can be used to calculate the transmitter's location.

TDOA is particularly useful in urban scenarios where signal reflections from buildings and other structures can play havoc with AOA systems. But, as pointed out by Schwolen-Backes, TDOA also has its shortcomings. "TDOA is not really widely used in tactical scenarios because it doesn't work well with narrowband signals, and with wide bandwidth signals, you have only short bursts in the time domain and vice versa. Also, for effective TDOA in tactical missions, you have to guarantee that you have a network link, which is often difficult in a very-fast-moving tactical situation."

Another DF or geolocation technique is a combination, or hybrid, of conventional AOA and TDOA approaches. Says Rohde & Schwarz's Strobel, "This technique applies to TDOA receivers and direction finders that can be used either in DF mode or switched over to TDOA mode. They can deliver both angle-of-arrival and IQ data (modulation scheme information) snapshots with high-precision time stamps. The combination combines the advantages of both methods and also compensates for their disadvantages. And, you can get geolocation with just one TDOA receiver/DF system." Strobel points to advanced software as one of the major improvements to DF/geolocation systems in recent years. "Most of our customers' missions are inside urban environments, where there is almost never a direct line-of-sight to the transmitter and many multipath propagations. Today, however, modern software algorithms and processing techniques can overcome these problems by overlaying all the DF results to make transmitter location accuracies of five meters. This seems remarkable considering past capabilities, but it is a reality now."

Power of Arrival (POA) is another parameter sometimes employed for DF or geolocation. However, although he acknowledges that the technique can sometimes be useful, Strobel says, of the three methods, POA is the weakest. "For example in an urban environment, the power level can easily drop by 20dB with nothing to do with distance-to-target, but just because you go underneath a bridge or into a tunnel, or the transmitter does the same." Strobel says he doesn't really see POA as helpful, although "one exception is when you're really close to a target. Although this wouldn't normally be the case for military applications, it could be useful to locate an emitter indoors."

Thales's Boyet also points to another DF technique, called Reference DF, that he describes as "not so new in principle, but recent in its operational use." Reference DF exploits the known characteristics of a targeted signal to help improve or speed up DF processing. The characteristics can be anything such as the signal channel bandwidth or a known training sequence used in over-the-air signaling. "With this pre-knowledge of the signal available to the process, DF can be significantly improved, which is particularly key in difficult environments such as urban areas."

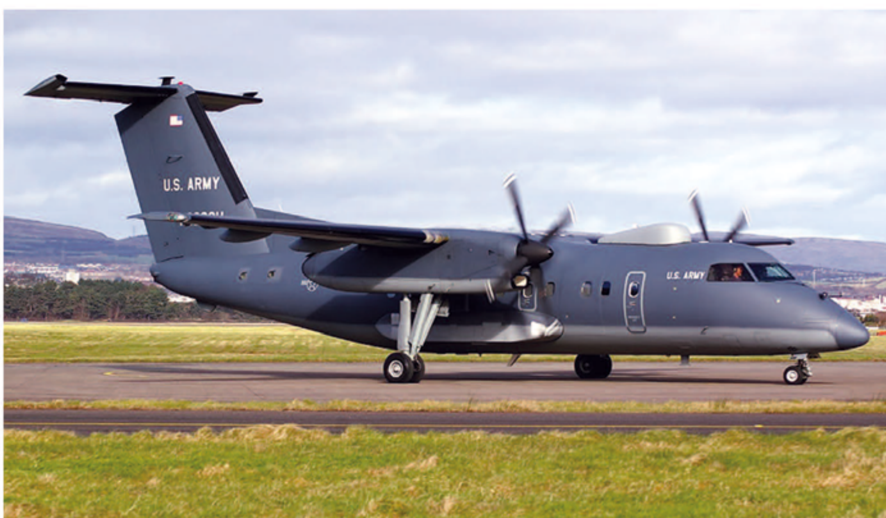
Today, many advanced DF/geolocation systems are based on correlative interferometry, a technique which calculates bearing based on the phase differences of a signal received at multiple, co-located, antenna elements usually arranged in a circular pattern. The approach is particularly useful for dealing with co-channel interference.

In high-signal-density environments, co-channel interference is a big challenge. Pointing out that HF systems continue to be used by both military and asymmetric threats for long-range communications, Thales's Boyet observes that co-channel interference is a particular problem for DF systems working in the band. "In HF, it's common to have two to four different signals coming from different emitters separated by thousands of kilometers in the same narrowband channel."

Thales applies the term high-resolution or super-resolution to the techniques they use for dealing with co-channel interference. The techniques require more antennas than traditional systems, as well as super-resolution algorithms. "Whereas a typical DF system may have 4-5 antennas, super-resolution requires in the range of 8-20. The more antennas you have, the more signals you can separate." The systems measure both the amplitude and phase of the signal. "Today, we need both," says Boyet. "Through the use of correlative interferometry, signals are simultaneously processed by multiple receivers using specific algorithms, which provide greater accuracy in all environments, but especially in complex environments."

Rohde & Schwarz's Atanassov, agrees. "The seamless integration of DF capabilities with automated signal processing allow you maximize outcomes as well as reduce size, weight and power (SWaP)." The company offers a 9-channel HF DF system with n-channel design (an equal number of antenna elements and receive channels, with no switching required.) In addition to standard correlative interferometric DF, the nine, parallel coherent receive channels perform beam forming and super-resolution."

At Plath, Schwolen-Backes says their state-of-the-art is a combination of correlative interferometric principles with vector matching. "We use vector matching to calculate both the amplitude and the phase of the detected waveform in parallel. This not only improves bearing accuracy, but is more robust against multipathing and polarization rotations. Sometimes it only makes sense to use one of the methods (amplitude or phase) depending on the antenna, but the vector matching principle delivers the best results."




## ADVANCED SOFTWARE AND PROCESSING

Continuing advances in processing hardware and software algorithms have made it possible for exponentially more intense signal processing and improved DF capabilities – capabilities essential for handling LPI signals. Says Schwolen-Backes, "The software algorithms are key to these advanced systems. The first step is the highly-sophisticated frequency and time resolution and then for the DF data signal analysis to see all the short bursts, ensure that they are measured correctly, and that the bursts are aggregated together to the correct signal independent of its spread over the spectrum. Finally, when you're talking about mixed sensors and multiple DF sites and receivers and their results, you have to ensure that all the data is fused correctly, so that you are seeing and hearing one complete signal."

As described by BAE's Vogel, "The important thing is that evolving technology focus on taking advantage of everything about a given signal that can be measured and processed to get the best answer most quickly in an increasingly challenging operating environment." In that regard, Vogel points to some of the key technology areas being pursued at BAE such as improving throughput for simultaneous DF measurement in both azimuth and elevation on many signals. "It's a fairly novel signal processing approach that does this, and it's really enabled by modern state-of-the-art processors and receivers, allowing it to be put into a tactical form factor." Another focus area is on improving the accuracy of, and increasing the convergence timelines for, geolocation in challenging environments. "Here, we're working on multi-path mitigation using some very advanced correlation techniques. A lot of DF techniques are based on correlation interferometry and modern processing allows you to do a lot of very fast processing on a very rich data set." Another BAE effort addressing operation in congested environments is aimed at measuring DF on multiple signals at the same frequency at the same time. "We have some novel techniques for doing that in a way that is very computationally efficient, allowing it to run on an embedded tactical system." Vogel also points out that, in addition to improving performance, it's also important to find ways to reduce system complexity, such as the complexity of the arrays, to ease the integration burdens on platforms. "It's always a cost driver and we're working on a novel broadband aperture that significantly reduces the number of antennas and their physical size."

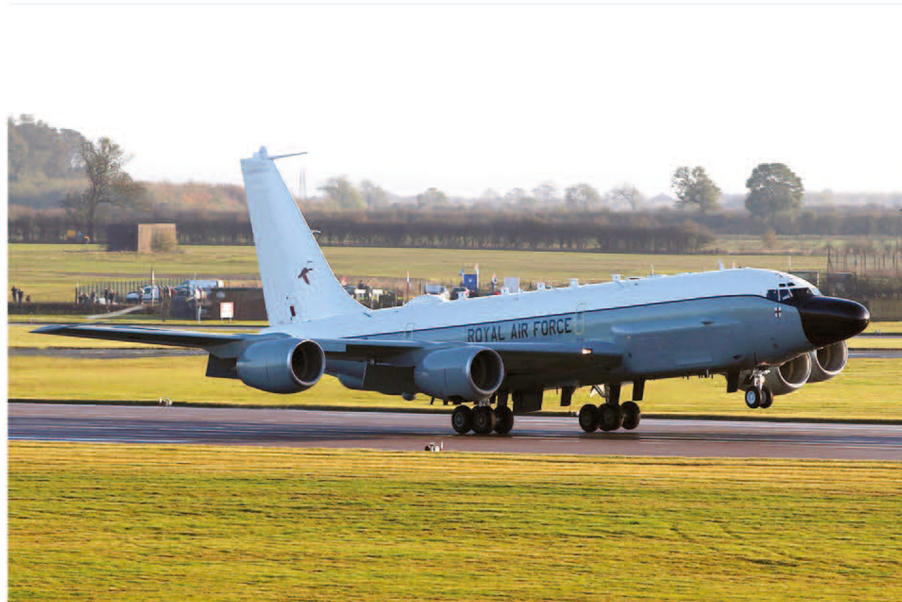
At Thales, Boyet says high-resolution DF techniques such as multiple signal classification (MUSIC) algorithms can significantly improve DF sensor performance over conventional approaches in all environments, "by separating the different co-channel signals, improving the signal-to-noise ratio for detection and DF, reducing signal fading and allowing for spatial filtering and beam-forming." To realize their true advantage, however, such techniques require significant equipment including multiple receive antennas, multiple receivers, and high processing capabilities (to reduce the switching of antennas to receivers).

Antenna switching is an important aspect of the processing requirement for DF/geolocation systems. While a single receiver may be able to cover the full frequency band of interest, individual antennas can't, with many different antennas required for the task. As described by Boyet, "Especially with tactical systems, since they won't have as many receivers as antennas, you need to switch multiple antennas to a given receiver, in order to cover a very wide frequency band." In addition to SWaP considerations, cost is also a major factor driving system design, the number of receivers, and ultimately the switching requirements.

Rhode & Schwarz's Strobel has noted another change in the spectrum in recent years affecting antenna design and use. "Over the last ten years, we've seen the emergence of new wideband digital signals for civilian digital video broadcasting (DVB) and digital audio broadcasting (DAB), and lots of them." Strobel says these low-power signals present a big challenge to active antennas (antennas with integrated signal amplifiers) because the antennas themselves cause intermodulation. For many applications and frequency ranges, however, active antennas are a requirement, because a passive antenna with the required sensitivity would be too big to be practical. Strobel says their approach to the problem is to use active antennas that can be switched to passive operation. "We can bypass the active part in our antenna so that the antenna element becomes passive, switching back and forth from active to passive mode depending on the strength of the signal. It gives you a tremendous increase in system linearity and reduces the inevitable intermodulation product."

## APPLYING AESA TECHNOLOGY

For the ELINT mission, Rockwell Collins' Rexford, sees "the overall changing dynamics of signal collection forcing changes in the collection mechanisms, capabilities through photonics receiver and signal processing technology. The goal is to get ultra-wideband processing at the aperture, and I think we'll see that over the next five years."




whether it's a spinning DF antenna which is high gain, or an interferometry antenna which collects on a pulse-to-pulse process but is lower in gain, or with the evolution of active electronically scanned arrays (AESAs) being used in the signal collection environment." Rexford points out that "it's not only the aperture that's important, but the processing as well, and the closer you can get the processing to the aperture, the higher the sensitivity. This allows you to better deal with radars in the low probability of intercept (LPI) environment."

In addition, he notes spread-spectrum signals require higher instantaneous bandwidth, and "this isn't a function of the antenna, but of processing capabilities and tuners. We have to develop wider instantaneous bandwidths (2 GHz, 4 GHz) and we're starting to see a move to this in some of the 'tier 1' nations." Even further out, Rexford sees the promise of extremely ultra-wideband instantaneous processing

Rexford says he sees AESA as an enabling technology to achieve these ultra-wideband capabilities. This is especially true, he says, for their use on attritable assets and applications like low-cost UASs in contested air spaces. "In future, we'll need to work inside of the threat environment, because the big antennas, big interferometers that currently drive DF and geolocation accuracies at range will be too big for the UASs. We'll have to get down to small, inexpensive arrays that the UAS can carry closer to the radar signals to improve and offset sensitivity levels.

Still, at present, Rexford admits there isn't a lot of advanced work in the area, and "it's more of a five-year-out trend. You have to get manufacturability costs down, and improve and adjust the algorithms and beams to handle multibeams simultaneously. I can see AESAs eventually replacing interferometry and DF spinning capabilities over time. It's the future state, but they have to be low cost to be feasible."

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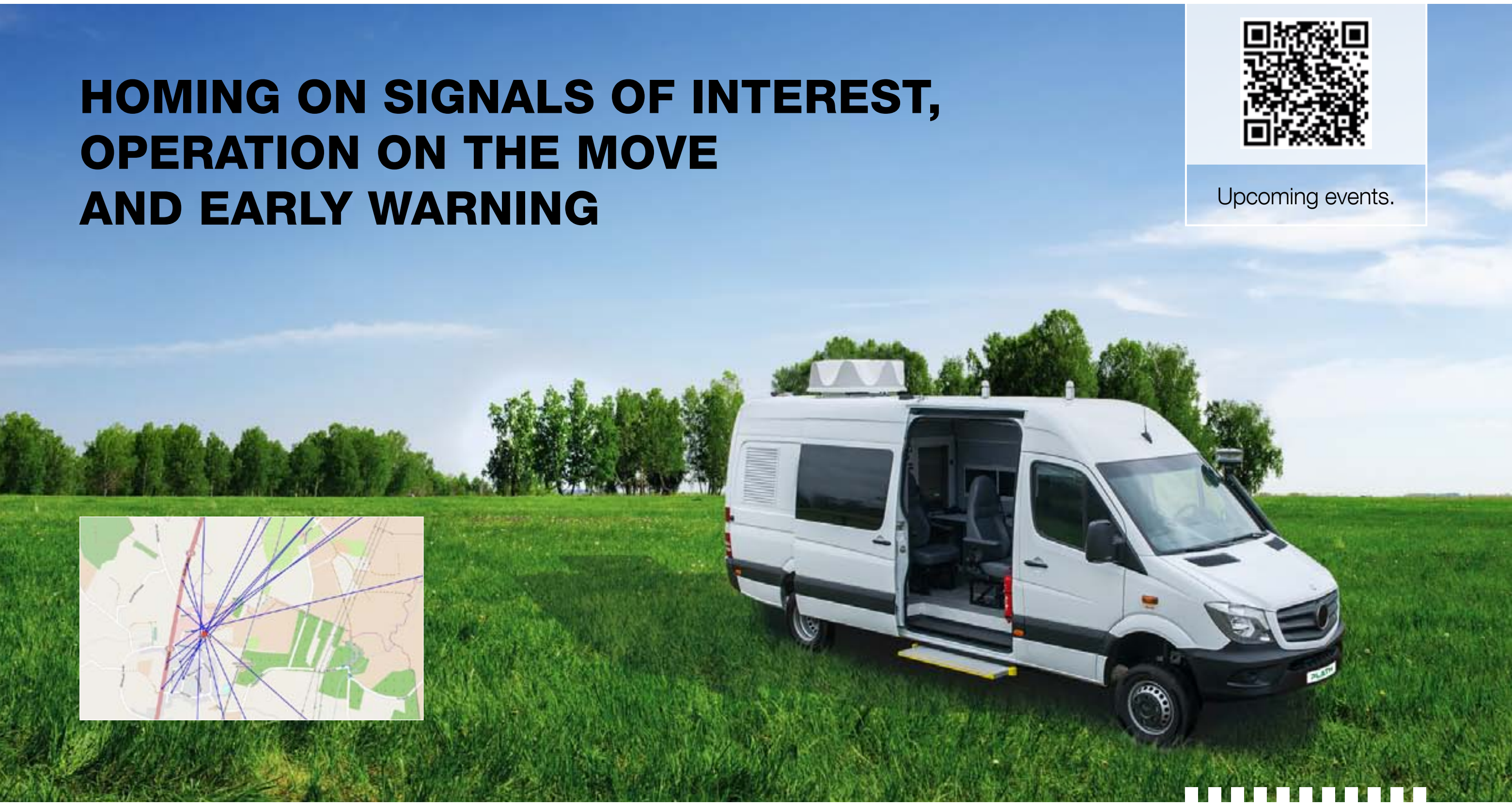


## Detect and locate emitters to identify threats

- HF-VHF-UHF direction finding (DF) for tactical and strategic missions
- Different DF principles and system setups to meet individual requirements and use cases
- Best performing sensors to detect even the weakest signals and the shortest bursts
- Sophisticated system behind the sensors to process mass data and correctly fuse results from different sensors
- High degree of automation to relieve the user from routine tasks
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