

REVIEW PAPER

Advances in Active Radar Seeker Technology

Rajatendu Das

Research Centre Imarat, Hyderabad-500 069.

ABSTRACT

Active radar seekers have gained wide applications in the terminal phase of missile guidance to provide hit-to-kill capability. Till recently, coherent monopulse tracker configurations were being used extensively for air-to-air missile seekers as well as surface-to-air missile seekers, while special real-beam technique-based seekers have been employed in antiship and land-attack systems. In this paper, features of active radar seekers have been described against different targets and background conditions to bring out the fact that the seeker design is highly application-specific in nature. The emerging trends in radar seeker technology have been identified wrt ever-changing threat scenario coupled with newer electronic countermeasure techniques, including the latest developments in components, subsystems, as well as implementation aspects.

Keywords: Active radar seekers, active electronically scanned array, antenna, missile guidance, seeker technology, coherent monopulse, tracker configuration, target tracking, target identification, target detection

1. INTRODUCTION

The superiority of radar seekers in missile guidance at the terminal phase has been well established since 1960s. Three basic configurations, viz., semi-active, active, and passive have been implemented in various types of seekers, including the track-via-missile concept used in Patriot missiles during Gulf War I. However, active radar seekers are the most popular in all the current missile programmes owing to their flexibility of design and implementation to suit almost every mission requirement apart from all weather capability. This is primarily due to the choice of waveform design, optimisation of receiver, and adaptability and flexibility offered by the digital signal processing techniques in vogue.

The most extensively employed configuration of active radar seekers so far realised is the coherent

monopulse tracker with a gimbaled antenna structure. In this paper, an attempt has been made to highlight the features of conventional active radar seekers and the associated current technologies, followed by the requirements of futuristic seekers, which have set the trend of radar seeker technology based on active electronically scanned array (AESA) antenna configuration.

2. BASIC ACTIVE RADAR SEEKER

The active radar seeker, from a radar engineer's view, may be defined as an application-specific compact missile-borne monopulse tracking radar whose antenna is mounted on a gyro-stabilised platform such that the antenna is isolated/decoupled from the body movement of the missile. The above basic idea stems from the requirement of generating highly accurate target information necessary for precise

homing guidance of the missile. A typical gimbaled antenna active radar seeker is shown in Fig. 1.

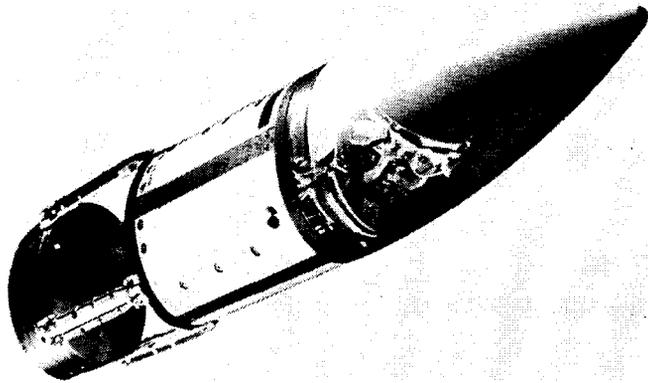


Figure 1. Typical active radar seeker

The active radar seeker essentially consists of blocks, shown in Fig. 2, configured as a coherent three-channel monopulse master oscillator power amplifier (MOPA) system capable of tracking the target in terms of angle as well as relative velocity (in terms of Doppler frequency shift, $\dot{\lambda}$) and range, R (optional).

To accomplish homing guidance, necessary guidance commands must be computed by the missile

computer known as onboard computer (OBC), which requires the measured value of rate of change of line-of-sight to the target wrt the missile. By keeping a continuous track of the target in terms of angle by the monopulse tracker such line-of-sight rate is computed which is self-explanatory.

Additional target information in terms of range and/or relative velocity (Doppler frequency shift) is used to identify and track a desired target among the other targets including clutter, if any. In Fig. 3, the operation of the active radar seeker has been shown in relation to the onboard computer responsible for overall guidance of the missile, which is self-explanatory.

The radar sensor, for most of the surface-to-air missiles (SAMs) as well as air-to-air missiles (AAMs), is configured as a high PRF (HPRF) pulsed (Doppler) radar frequency essentially as a Doppler tracker apart from being a basic monopulse angle tracker. Frequency of operation varies from X-band to Ku-band for SAMs and AAMs to millimeter wave frequencies (35 GHz and 94 GHz) for SAMs in air defence role. Seekers for precision-guided munitions (PGMs) and antitank missiles (ATMs) also operate at these millimeter wave frequencies. However, it may be noted that for antiship missiles (ASMs), ATMs and PGMs, the radar waveform is

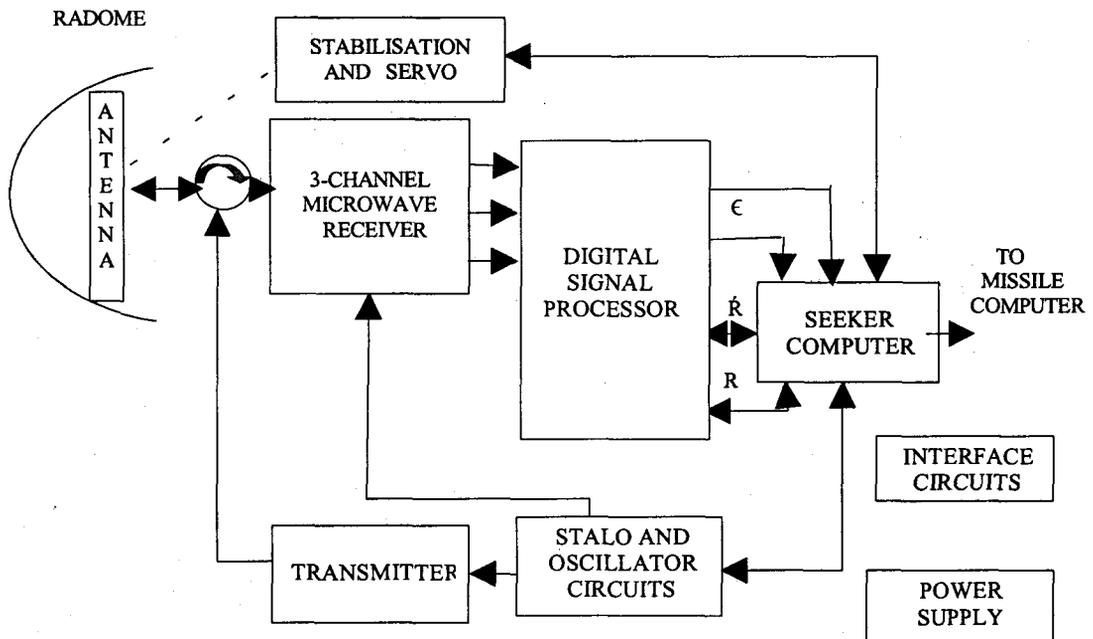


Figure 2. Active radar seeker - basic blocks

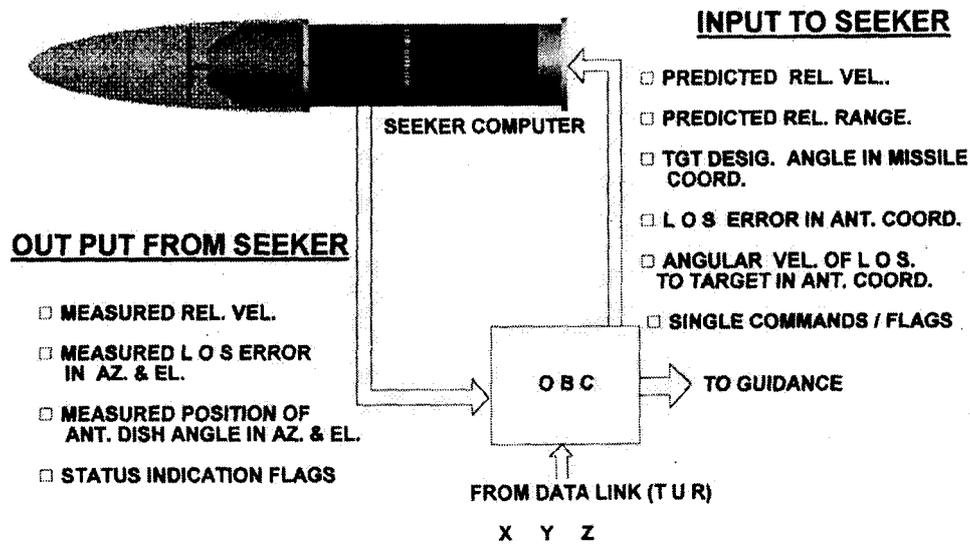


Figure 3. Active radar seeker operation with onboard computer

specially designed for slow-moving target detection and identification.

3. EXISTING RADAR SEEKER TECHNOLOGIES

The existing technologies for each of the subsystem of a radar seeker are as follows:

3.1 Radome

The variable thickness radomes as well as thin-walled radomes based on slip-cast fused silica / glass-filled polycarbonate (GFPC) technologies have been widely used with radome error slope variation compensated by special manufacturing process or by correction method incorporated in the angle error extraction circuit.

3.2 Antenna

The slotted planar waveguide array antenna weighing less than 500 g with an integrated microwave receiver, has been used in most of the latest conventional seekers.

3.3 Stabilisation System

The high precision-gimbaled mechanical system with low outline has been used with the gyro of the inertial navigation system providing reference

for seeker stabilisation (strapped-down configuration).

3.4 Transmitter

The master oscillator power amplifier (MOPA) configuration using travelling wave tube (TWT) / klystron has been extensively used. The transmitter based on injection-locked magnetrons has been developed. Solid state power amplifier driver along with microwave power amplifier (tube-based) has been implemented following the concept of microwave power module (MPM) where power-added efficiency is maximised.

3.5 Receiver

Almost all the seekers currently use state-of-the-art triple-super heterodyne MMIC-based receivers with a very low-noise figure (< 2 dB).

3.6 Signal Processing/Data Processing

Intensive application-specific integrated circuit-based digital signal processors have been developed to suit the application-specific requirements. However in some radar seekers, wide dynamic range requirements have been met using crystal filter-based analog signal processing in the front high-frequency receiver section. System-on-chip approach is being attempted.

3.7 Waveform Design

Currently high/medium PRF pulsed waveform is widely used. However, in some seekers for ASM application, pseudo random phase-coded waveform has been used. The complex waveform design is the latest trend to combat electronic countermeasure techniques and provide automatic target recognition capability.

4. CHANGING REQUIREMENTS

With the advances in ECM techniques, stealth technology, and target operational performances, eg, manoeuvrability and speed, the following new requirements need to be considered for seeker design:

- Low peak power for reduced vulnerability of detection as well as less demanding power supply system
- High power aperture product for increased range
- Optimum waveform design for advanced ECCM features
- Wide bandwidth operation for providing frequency agility (pulse-to-pulse/batch-to-batch, or in pseudo random fashion)
- Multisensor data fusion being implemented through data link/INS-GPS
- Faster signal processing for large data handling and also for imaging
- Low radar cross section detection and tracking capability to meet stealth technology advancements
- Low weight / low volume / high-density packaging and efficient thermal management for miniaturisation
- Use of commercially off the shelf (COTS) components for the development of low-cost seeker (as seeker costs 70 per cent of missile just for a price of kill)

The above requirements have pushed the radar seeker technology to adopt entirely newer concepts and has led to the development of the following new concepts:

4.1 Noise Radar Seekers

Noise radar seekers refer to the seekers whose transmitted waveform is random or random-like in contrast to conventional pulse, continuous, frequency-modulated continuous wave waveform. The inherent advantage with this noise radar seeker is its low-cost. The noise radar seeker transmits a very wide band random noise signal. It makes a copy of what it transmits and correlates it with the return signal. To function, the seeker processor and converters must clock at > 1 GHz speed. This design is made possible by the recent advances in high-speed digital signal processing technology. The salient features of this technology are:

- Extremely high bandwidth, which in turn gives high-range resolution. Range resolution up to 15 cm is possible with noise radar seekers.
- Simultaneous measurement of range and Doppler with high accuracies
- Jamming resistance (good ECCM capability)
- No ambiguities

4.2 MMW-Pseudo Random Code Seekers

The millimeter wave (MMW) radar seekers have become attractive option in many seeker applications, including PGMs and imaging sensors. These have undergone extensive evaluation over the last decade, offering a route to achieve miniaturised seeker. The latest developments aim at completely solid state, highly reliable, and low-cost systems. Two configurations, viz., pulsed and frequency-modulated continuous wave (FM-CW), have emerged as the favoured solutions for the first generation of smart weapon applications. However for both of these implementations, complexity of the millimeter wave technology does pose a significant technical challenge. The pulsed radar system requires higher power, and therefore, expensive transceiver circuit to meet the signal-to-noise ratio requirement, while FM-CW system offers the advantage of simple and low-cost transceiver circuitry, but has stringent transmitter/receiver requirements.

The pseudo random code (PRC) radar offers simultaneous high-resolution measurements of target range and Doppler for the same power aperture product with a simple transceiver but having a complex signal processor. Rapid advances in semiconductor technology will provide the necessary high density, high-speed realisation.

5. LIMITATIONS OF THE EXISTING SEEKERS

A fast responding angle tracker, for active radar seeker application, is highly desirable for the new generation missiles to counter high velocity, highly manoeuvrable targets. In a conventional gimbaled antenna seeker, it is the response of the electro-mechanical servo system, which ultimately decides the overall seeker performance in terms of speed and precision. The key parameter in this regard is the mechanical inertia of payload of the servo system, ie, the antenna system. Therefore, the current seeker technology tends to employ low weight (< 500 g) slotted planar array antenna system with low outline (thickness < 5 mm). Still, the response of the servo system is limited to within 250°/s for a step-input designation while catering for a line-of-sight rate up to 30°/s, for a reasonable antenna diameter (Approx. 300 mm) inspite of tight mechanical tolerances. Also, this occupies relatively more space and has more power consumption, apart from being potentially vulnerable to electronic countermeasures due to its sluggishness.

The second constraint of the conventional gimbaled antenna seeker originates from an entirely different phenomenon. This is due to achievable radome error slope within the required scan angles caused by the presence of radome as against the limit of radome error slope value permissible to ensure adequate missile stability with an acceptable miss-distance.

For this reason, the radome error slope measurement data is extremely important and the two distinct methods are used to limit the radome error slope value as described below:

- In the first method, the error slope is continuously measured during radome fabrication and

appropriately corrected during the process. In this case, each radome is cleared after conducting the test with a standard seeker antenna.

- In the second method, a complete data of radome error slope measurement in all possible planes is stored in the seeker computer which is used as the digital signal processor for appropriate compensation in the angle-processing channel, bringing down the radome error slope effect within the acceptable limits.

While the first method can reduce the radome error slope down to 3 per cent, the second method brings down the value to approximately 1.5 per cent. It may be mentioned here that in some specific cases of a highly manoeuvring target with high relative velocity, the above radome error slope value may become unacceptable.

It is also to be noted that in the second case of radome compensation, the particular radome-antenna combination becomes a unique pair. If either the radome or the antenna is damaged, the measurement of radome-antenna combination needs be re-done and the signal processing re-programmed.

6. CURRENT TRENDS IN SEEKER DEVELOPMENT

To overcome the above limitations of existing seeker performance, the current seeker technology is looking for alternative approaches like active electronically scanned array (AESA) seeker. The fundamental difference that the active electronic scanning provides is the instant beam switching across a zone of coverage, equivalent to gimbal angle freedom, without moving the antenna physically, thus avoiding sluggish electromechanical drive mechanism. The concept of active electronic scanning array seeker has come up following the development of small size (~ 10 mm x 10 mm x 50 mm) T/R modules at J-band. These can be packaged within the space available for seeker application. The operation of the seeker is actually accomplished by adopting phased array technique. This approach has the additional advantage of forming a null in the direction of a jamming signal source, thus reducing the effectiveness of jamming. Each element of the

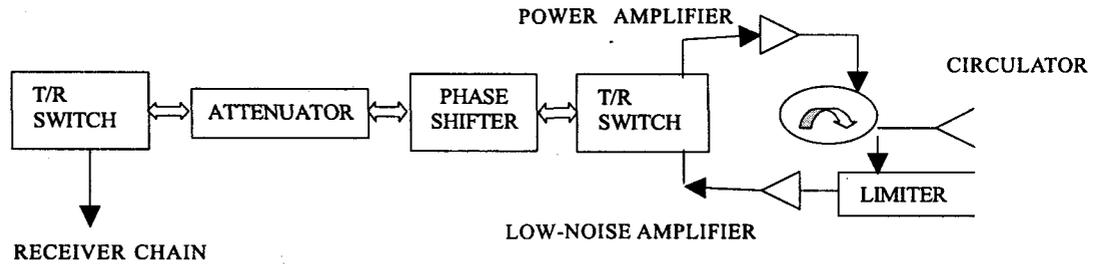


Figure 4. Typical T/R module

electronic scanning array has its own power amplifier, thus making each element active and the array, an active electronic scanning array, which refers to a number of such modules complete with radiating elements (patch antenna or slots) forming the radiating beam in space through an appropriate phase and amplitude control by a beam control network. This has been made possible using microwave integrated circuit, monolithic microwave integrated circuit technology apart from incorporating RF microelectromechanical system (RF MEMS)-based components. However, AESA, while quite attractive, is rather complex and expensive as on today. A typical T/R module is shown in Figure 4.

In the basic form, as shown in Fig. 4, the T/R module consist of a power amplifier in the transmit chain, low-noise amplifier in the receive chain in conjunction with phase shifter as well as attenuator control common to both. Therefore, overall system power efficiency is increased as both the transmit power amplifier as well as receiver low-noise amplifier are directly connected to the radiating antenna via the circulator/limiter, resulting in less RF loss. Therefore, the active array provides more efficient power-aperture management combined with rapid beam steering capability, leading to enhanced detection and tracking performance. Needless to mention that these are highly desirable features for active radar seeker functioning. As in a conventional strapped down seeker, the beam steering reference can still be obtained from that of inertial navigation system. It is further noted that the T/R module configuration is readily amenable to coherent detection, a primary requirement for Doppler processing.

A pictorial representation of a packaged T/R module-based AESA seeker is shown in Fig. 5,

while in Fig. 6, the photograph of an electronic scanning array (ESA)-based seeker (Philip Lacomme, THALES airborne systems, presented in IRSI 2003) is provided.

It is noted from Fig. 4 that the main lossy component in the T/R module is the phase shifter having an insertion loss of 9-10 dB at J-band. Being common to both the transmit and the receiver chains, it demands more power from the transmitter as well as more gain from the receiver amplifier. Considering state-of-the-art MEMS technology, the *GaAs* phase shifter can be replaced by a MEMS

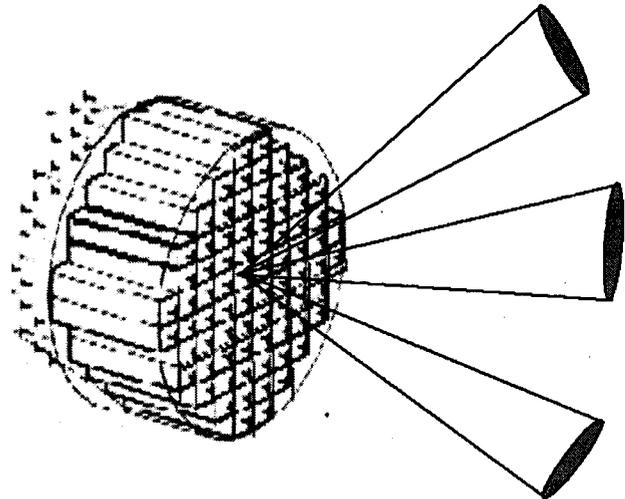


Figure 5. Pictorial representation of active electronically scanned array seeker.

phase shifter with only 1 dB insertion loss at J-band. This gives an advantage of about 8 times less transmitting power and 9 dB more dynamic range in the receiver chain. The EMS-based approach of ESA seeker is shown in Fig. 7.

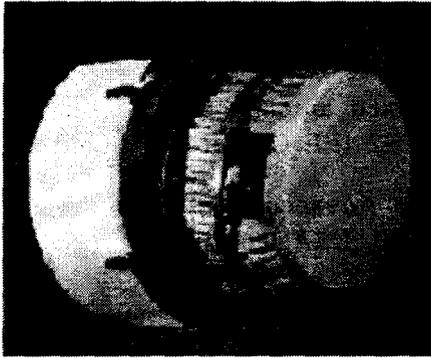


Figure 6. Electronically scanned array-based seeker

While the current technologies will push the realisation of the MEMS-MMIC ESA seeker, which is evident from the published literatures and development sources as shown in Fig. 7, perhaps conformal printed circuit-type antennas fixed to the body of the missile show the potential to overcome many of the fundamental problems associated with the conventional seekers, including the radome error slope compensation. These have the advantage of being conformal to the skin of airframe, and hence, do not consume the internal volume of seeker nose cone portion. This can be a real advantage. As a class of antennas, these exhibit definite advantage over the gimballed precision antennas. However, there are generally trade-offs for degraded electrical performance at specific scan angles. Photograph and schematic of a typical conformal array seeker is shown in Fig. 8, the ultimate dream of seeker technology.

7. CONCLUSION

The class of seekers, using radar imaging technique, have not been brought out in view of paucity of information except of the seeker in Pershing-II, which performed real-beam mapping through de-convolution technique but currently not in use. While the seekers for antiship missiles perform a limited sector scan to identify the designated target using PRC waveform, effective hit of a land-based target is still performed using imaging infrared seekers.

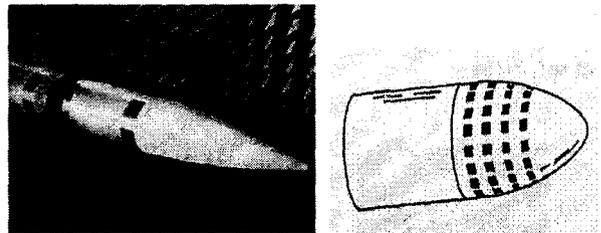


Fig 8. Conformal array seeker

At par with the development of seekers, highly sophisticated simulation techniques and related software as well as test setups have come up, enabling complete evaluation of seeker performance under dynamic conditions through HWIL tests. In addition, mathematical modelling and theoretical prediction techniques have matured to the extent of highly convincing and acceptable results validated through the experiments.

ACKNOWLEDGEMENTS

The author is grateful to Director, Research Centre Imarat, Hyderabad, for his constant encouragement and support towards seeker technology development in an integrated manner matching with the latest trends and bringing out this paper. The author also wishes to acknowledge for the motivation and encouragement by Shri N. V. Kadam, Emeritus Scientist. Lastly, the support rendered by Shri C.G. Balaji, Scientist F, Ms A. Mangatayaru, Scientist D, and Shri B. Someshwara Rao, Scientist C in completing this paper is sincerely acknowledged.

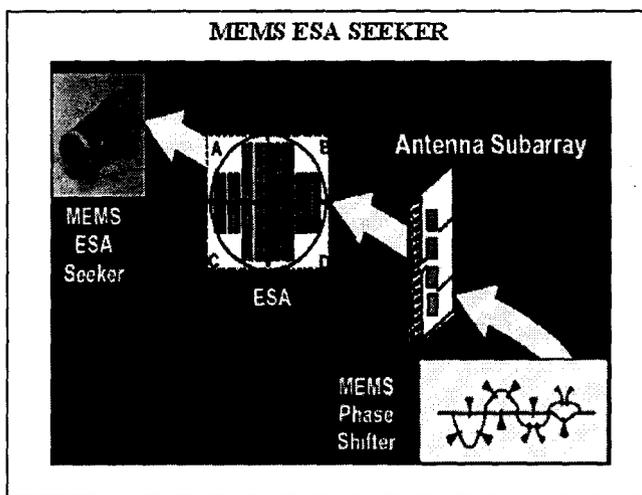


Figure 7. MEMS electronically scanned array seeker

REFERENCES

1. Millimeter and microwave engineering for communications and radar, edited by James C. Wiltse.
2. Jane's, missiles and rockets, June 2003, Vol.7(6).
3. Test and evaluation of the tactical missile, edited by Emil J. Eichblatt, Jr. Vol. 119, Progress in Astronautics and Aeronautics. AIAA Tactical Missiles Series.
4. Body-fixed antenna options for seekers. *In* Radar '92 IEE Conference Publication.
5. Defense Advanced Research Project Agency (DARPA), USA website.

Contributor



Mr Rajatendu Das received his BE and ME (Electronics & Telecommunication Engg) both from the Jadavpur University, Kolkata, in 1971 and 1973. He joined Defence Research & Development Laboratory (DRDL), Hyderabad, in 1976 as Senior Scientific Officer, Gde II. Currently, he is Technology Director, RF Systems at the Research Centre Imarat (RCI), Hyderabad, leading a team of scientists engaged in the development, production, and testing of radar systems for missile applications. He is involved in research on various active radar seekers and state-of-the-art MEMS-based RF system development programmes.