SOLID STATE DRIVEN MODERN EW SYSTEMS ARCHITECTURE

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Abstract — **This paper focuses on the applications of Active Phased Array (APA) technology in Electronic Warfare (EW) systems. The use of APA technology in EW systems allows to extend the capabilities of traditional EW system both for Electronic Counter Measure (ECM) as well as for Electronic Support Measure (ESM) functionalities.**
The jamming functionality takes full advantage of the use of APA technology thanks to the very high Effective Radiated Power (ERP), the graceful degradation, the fast beam switching capability and the multiple beams functionality.
The APA provides benefits also the system ESM capabilities, especially in conjunction with state of the art Digital Signal Processing technology, allowing to implement High Sensitivity ESM, High Accuracy Direction Finding (HADF) functionality, closed loop monopulse emitter tracking, Side Lobe Blanking (SLB) measurements, etc. Particular attention is paid to the benefits of the future GaN technology, and to the innovative system concept of shared apertures.
Finally, the use of APA allow also to improve the EW system life cycle cost, since it guarantees full maintainability due to the intrinsic modular design.

Keywords — **EW, APA, Jamming.**

I. INTRODUCTION

Modern EW requirements imply system architectures basically capable of providing emitter signal discrimination and selective jamming responses in all the radar operational domains: time, frequency, space, on pulse modulations (MOP) [1].

The optimum solution can be found exploiting the emerging technologies:

- High sampling rate Analog to Digital Converter (ADC);
- Digital Signal Processing (DSP) implemented in the new powerful devices (ASIC, FGPA, SOC);
- Dedicated functional units to process the signals: Digital Radio Frequency Memory (DRFM), Digital Receiver Boards (DRX), Time Of Arrival Predictor board (TOA TRACKER);
- Solid-State microwave technology (GaAs/GaN) for power generation: Active Phased Array (SS APA) [2].

Gallium Arsenide (GaAs) microwave devices are today extensively used in EW application and they have already reached their maturity and their ultimate limits in terms of deliverable power, efficiency and thermal management. The new Gallium Nitrite (GaN) technology is promising to open new frontiers to the microwave power components providing more robust RF front-ends and more powerful solid-state RF transmitters at a lower “cost per Watt”.
These promising features can become key design drivers in pushing the “fully solid-state” EW system architecture.
“Fully solid-state” EW system is today a reality for many applications, but thanks to GaN it could be extended to all the EW fields.
GaN HEMT as next generation microwave devices have several potential benefits at system level:

- An order of magnitude higher power density, allowing
  - ✓ higher output power with the same chip sizes that means higher performances;
  - ✓ lower sizes with the same output power that means lower chip-set cost;
- Higher supply voltages, so:
  - ✓ DC-DC converter is not required and system efficiency is improved;
  - ✓ power distribution is simplified;
- Improved thermal conductivity of the substrate (i.e. SIC) and increased operating temperature that implies:
  - ✓ lower requirements for the cooling system allowing a cost reduction;
- Better noise properties and higher robustness may allow limiter removal with many advantages:
  - ✓ space and weight saving;
  - ✓ insertion loss reduction and higher sensitivity;
  - ✓ assembly simplifications allowing cost reduction;
- Robust TR switches may replace the traditional circulators
  - ✓ higher level of integration allowing cost reduction.

II. DRX BASED ESM ARCHITECTURE

Wide instantaneous Bandwidth DRX provides frequency canalization of the incoming signals with adjustable channel bandwidths in order to achieve:

- High sensitivity;
- Intra-pulse analysis;

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- Multi- signal discrimination.

Modern fast techniques for emitter ranging and location are based on differential measurements of emitter signal phase and time of arrival:

- A " twin RX apertures" antenna system, based on two antennas located in different positions, is employed to measure different parameters of the received signal through a dual DRX;
- Each aperture should provide both Horizontal and Vertical polarizations to match the threat signal polarization.

III. DRFM BASED EA (Electronic Attack) ARCHITECTURE

Adjustable Bandwidth DRFM provides frequency selection of emitters, signal storing, coherent jamming and enables time-based signals decoupling:

- Pulse Reconstruction from signal slice;
- Pulse storing and replaying;
- Pulse chopping.

Time sharing is optimized through an adaptive scheme, based on TOA trackers, which allows:

- To counter multiple simultaneous threats;
- Jamming Programs tailored to each individual threat;
- Prediction of jamming activity in order to provide effective threat countering and interoperability management.

IV . ADVANCED ERP GENERATION

The most important figure of merit of the EW transmitters is the Effective Radiated Power (ERP) defined as the product of the available power at the generator output and the antenna gain.

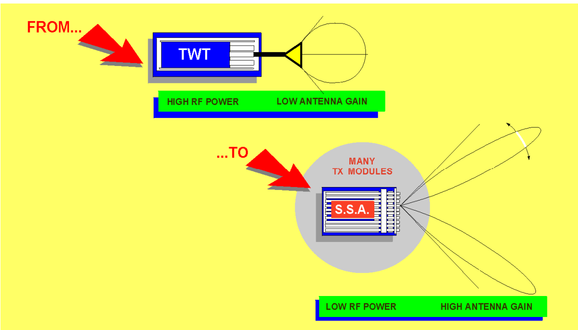

Fig.1 Different methods of ERP generation

Once the angular coverage is specified, the required ERP can be generated either with a powerful generator (TWT based) and a low gain antenna with beam wide enough to respect the specified angular coverage or better with an Active Phased Array (APA) antenna characterized by a number of small amplifier modules including phase shifters and directly connected to the own radiating elements (Fig. 1, Fig. 2). The APA provides narrow beam width and a high gain that contributes to the ERP generation allowing the use of relatively low power Solid State Amplifiers (SSA). With the adoption of Transmitting/Receiving (T/R) modules, the narrow beam is instantaneously (tens of nanoseconds rate) scanned within the specified coverage by the phase shifter setting in the same direction from which the signal has been received (DOA), providing the following advantages:

General:

- Electronic beam stabilization;
- High electromagnetic compatibility;
- Low weight & power consumption;
- Low RCS.

Transmission:

- High ERP with 100% duty cycle;
- Wide angular coverage (azimuth and elevation);
- High angular selectivity;
- High efficiency;
- High availability (graceful degradation).

Reception:

- Reduction of EM scenario pulse density due to angular selectivity;
- High sensitivity;
- High D/F accuracy (azimuth and elevation) and beam self steering.

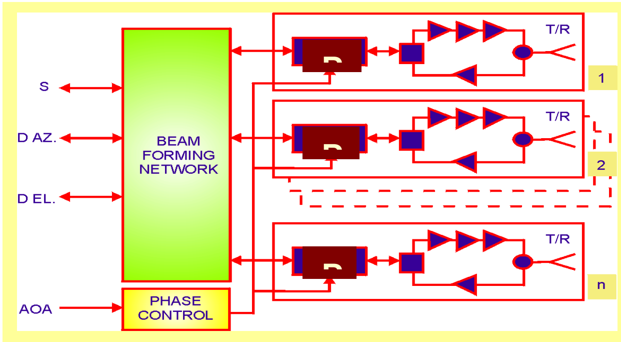

Fig. 2 - APA : Active (RX/TX) Phased Array

V. MODERN SELF-PROTECTION ARCHITECTURE

Advanced on board angular deception techniques are today available using the "Twin RX/TX Apertures " architecture implemented with modern technology. This allows to generate "smart" interfering jamming signals with appropriate phase/amplitude relationships on radar antenna:

- A "Twin RX/TX Apertures " antenna system is based on two RX/TX phased array antennas located in different positions, each provided with an "Ortho-Polarized element " (H/V), and feeding a dual DRFM.

- Relative phase, amplitude and polarization of jamming signals can be accurately controlled in order to implement WFD as well as Adaptive-XPOL.

V.1 TERMINAL THREAT ADVANCED COUNTERMEASURES

The described emerging technologies allow the implementation of advanced countermeasures based on angular deception also against the mono-pulse radars typical of the terminal threats.

Digital Radio Frequency Memory (DRFM) and Solid State Active Phased Array (SS APA) are the enabling technologies for the WFD and XPOL countermeasures that have been extensively field demonstrated effective as deception jammer techniques against mono-pulse radars.

The Wave Front Distortion (WFD) technique is based on the generation on the victim radar antenna of a phase front slanted with respect to the plane orthogonal to the direction of propagation inducing an angular tilt of the mono-pulse antenna. The technique can be realized exploiting a couple of SS APA antennas installed at a minimum distance "d" and a double DRFM in a reciprocal circuit allowing the signal received by the first antenna to be transmitted by the second one and vice versa. It is worthwhile to underline that this technique generates a fixed "displacement error" D (meters), therefore the angular error α (α = D /Range with D equal to a constant and established by the jammer) is quite small when the threat is still far and becomes significantly important as the threat is approaching the target. For this reason the technique can be defined as a short distance technique.

The Cross – Polarization (XPOL) Technique is particularly effective against old style parabolic reflector mono-pulse antennas. It is based on the peculiarity of this type of antennas whose mono-pulse characteristics Δ/Σ measured in cross polarization is angularly displaced with respect to that measured in nominal polarization. It is worthwhile to underline that this technique generates an angle offset, proportional to the victim radar antenna Beam Width (BW), therefore the angular error is independent on the threat distance (α = K*BW) while the displacement error will be reduced as the threat is approaching the target (D = Range* α). For this reason the technique can be defined as a long distance technique.

V.2 SS APA FOR AIRBORNE SPJ

Solid-state phased array technology allows high ERP, compact, efficient and light ECM airborne equipments for self-protection applications. The fig. 3 shows a typical SS APA suitable for A/C, HELO and UAV, and particularly for installation in small pods or pylons. The compact unit includes the radiating element array covered by a cylindrical wave polarizer, a set of RX/TX modules directly connected to the radiating array, the control boards that receives the command from the ECM processor and convert it in amplitude and phase setting of the RX/TX modules, its own power supply and the cooling system.

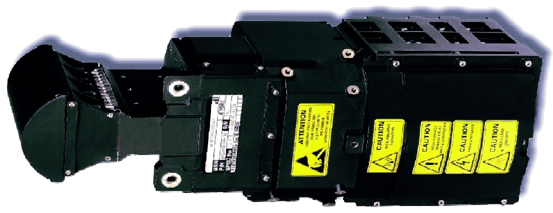

Fig. 3 - SS APA for airborne self protection

V.3 SS APA FOR NAVAL SYSTEMS

The ERP requirement is always proportional to the Radar Cross Section (RCS) of the platform to be defended. In the naval application an ERP of hundreds of KW is required especially if the mutual protection (Area Protection) is specified. A number of hundreds RX/TX modules is required for such ERP generation. In order to overcome the cost, dissipation, cooling issues, the RX/TX module architecture can be designed to have a double output connector both in reception and in transmission modes. Through the exploitation of a parallel HEMT structure combined by a dual hybrid circuit, the switching between the two connectors can be accomplished at low power level (before the HPAs) and the switching time can be kept within few tens of nanoseconds. Thank to this structure, each RX/TX module can be connected, trough low loss RF cables, to two homologues radiating element pertaining to two different planar arrays 90° slanted each other. In this way a unique SS APA can cover more than 180° in azimuth and 90° in elevation. The fig. 4 shows an example of a naval SS APA designed for Self Protection and Force Defence.

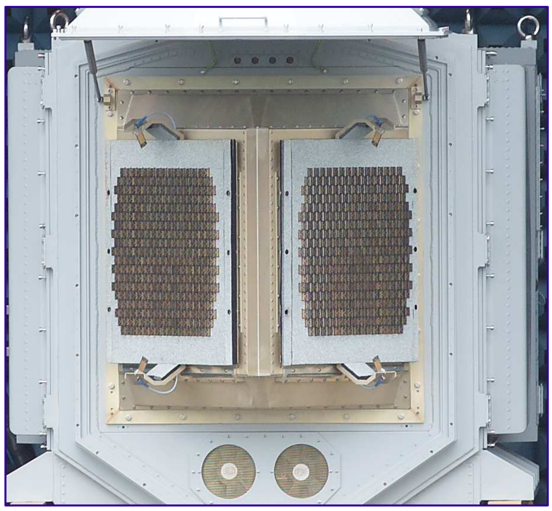

Fig. 4 SS APA for NAVAL SPJ & Task Force Protection

V. 4 SS APA FOR SUPPORT JAMMER

Different operational requirements are commonly indicated as "Support Jammer". In the airborne attack a first distinction is to be made between Stand Off Jammer, Escort Jammer and Close In Support Jammer.

In the Stand Off mission, the EW Aircrafts stands off the enemy Air Defense range and creates, disturbing the radars, a penetration corridor for the friend aircrafts.
In other cases the EW Aircraft proceeds together with the penetrating formation either standing outside the Point Defense ranges, and in this case we'll talk about Escort Jammer (EJ) or it can follow the intruder formation up to the Target. In this last case we'll call it Close In Support Jammer (CSJ). In many cases, but especially for the Escort and Close In missions, the requirements deal with a Full Band Jammer with a complete coverage from C to J band and 360° azimuth coverage to contrast both the search and the point defense radars. High power RX/TX Solid State modules operating in the C-D and E-J radar frequency bands allow affordable Jammers for:

- ✓ Self-Protection (LBJ / HBJ)
- ✓ Support Protection (SOJ, CSJ, EJ)

The fig. 5 shows the complex architecture of a full band modern support Jammer. A common EW processor collects the data from the Radar ESM and Communication ESM. The four SS APAs provide further accuracy and sensitivity to the ESM function. After designation an APA is selected for radiation on the basis of DOA and frequency band. Each set of RX/TX modules, either in High Band or in Low Band feeds a dual orthogonal aperture that guarantee the 180° instantaneous coverage.

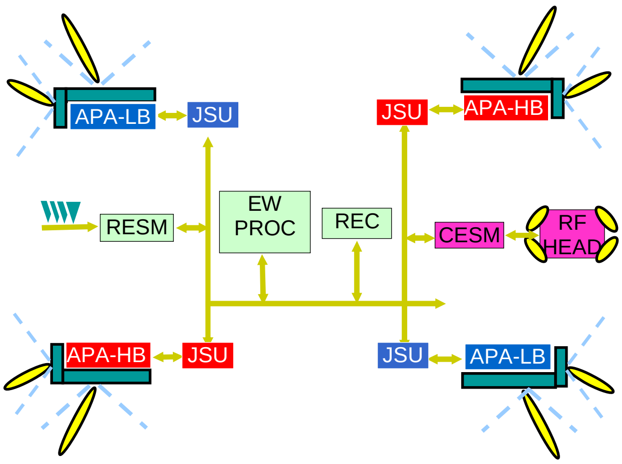

Fig. 5 - Full band Support Jammer Architecture

V. FURTHER EW ARCHITECTURE EVOLUTION

Robust and powerful broad band RX/TX modules allow the same phased array antenna aperture to be shared by multi RF systems. Electronic Attack architecture, based on "Twin RX/TX Apertures ", can share RX/TX phased array antennas to provide ESM subsystem with accurate emitter D/F, Ranging, Location and ensuring a robust ESM Front-End (Fig. 7).

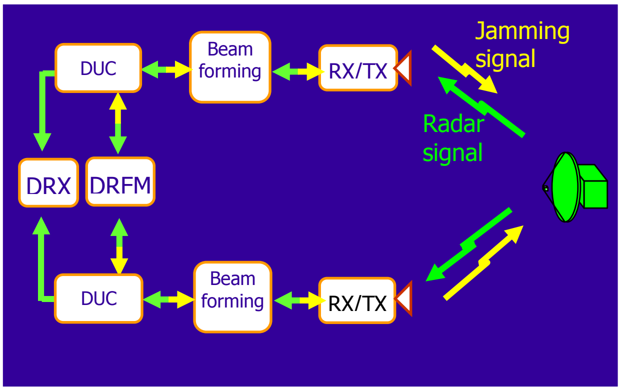

Fig. 6 - Integrated EW Architecture

ESM function could exploit the whole aperture or a limited sub-aperture depending on the actual mode being performed:

- large beam width (from a few element sub-array):
  - ✓ H/V polarisation emitter signals acquisition;
  - ✓ High accuracy D/F;
- narrow beam width (from the full array):
  - ✓ Emitter acquisition for high SNR signal measurements;
  - ✓ LPI signals emitter search and detection.

From the parallel evolution of DSP and GaN devices, a higher level of integration for multi RF functions is expected in a near future: a common aperture will be shared exploiting a dedicated switching matrix; Down-Up Converters (DUC) and common ultra-fast A/D sampler will provide direct input to the Digital Radio Frequency Memories for the EA functions and to the Digital Receivers operating real time FFT for the ESM functions in both the radar and communication frequency bands. Wide Band RX/TX modules and appropriate thermal solutions appear to be decisive to enable shared aperture systems integrating all RF functions:
ESM + EA + RADAR + COMMUNICATIONS (Fig. 7).

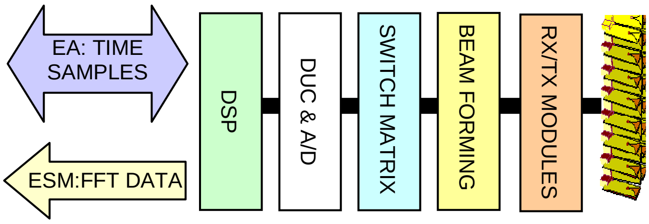

Fig. 7 - Shared Aperture multi-functional architecture

VI. SS APA ENABLING TECHNOLOGIES

Active Phased Arrays, operating in such wide frequency band require key components:

- Frequency independent radiating elements with low mutual coupling characteristics and constant beam-width allowing beam scanning in a large angular sector without important losses (Fig. 8);

Fig. 8 - Modular sub-array radiating elements

- Beam Forming & Beam Control networks to derive from the same aperture different simultaneous radiation patterns for the different array functions: Monopulse Direction Finder, emitter tracking, Jamming (Fig. 9);

Fig. 9 - Beam forming network of a planar array

- RX/TX Module covering at least a 3:1 frequency band, with the full control of input/output amplitude and phase and possibly with multiple output to independently control the polarization characteristics of the received and transmitted wave (Fig. 10).

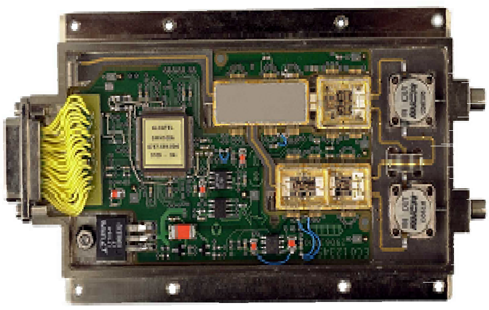

Fig. 10 - Dual output SS RX/TX module

VII. FUTURE GaN OPPORTUNITY

Recent R&D results from the USA allow to foresee the incoming of a new generation of RX/TX modules based on GaN technology with better performances expected

- 0.5-6 GHz MMIC HPA;
- 5-18 GHz MMIC HPA.

The following figure shows the ERP achievable from APAs as a function of the number of radiating elements/TX modules and the output power delivered from each module. Different lines are shown for different power achievable with GaAs technology and with GaN technology. In the same figure two dotted lines indicate the typical ERP required for Airborne self-protection Jammer and for Naval Force defence . It is worthwhile to notice that the number of modules required to obtain a given ERP figure decreases as the output power of the modules increases but not linearly. This is due to the contribution of the array directivity to the ERP figure.

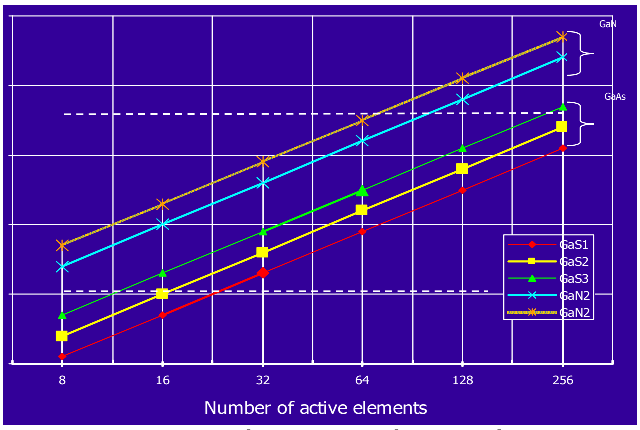

Fig. 11 - ERP vs. element power and array population

Since the year 2005 many European Companies and Institutions have been involved in government funded R&D to establish an independent European supply chain for the manufacture of GaN HEMT devices and MMICs. They have started from the substrates selection and epitaxial growing, the elementary models, to the demonstrator test devices, MMICs, up to the integration prototypes and demonstrators and thermal management. The obtained promising results permit to confirm a list of advantages, already envisaged from the USA studies:

- The ability to operate at higher temperatures (higher maximum junction temperature: up to 300° C) extends the applications where ambient air cooling is usable. It reduces the power consumed by the air cooling system thus increasing overall system efficiency;
- Better substrate (SiC) thermal conductivity allows easier heat drain;
- Output power more than doubled with respect to the GaAs devices (theoretically ten times);
- Higher break-down voltage (up to 60/70 V);
- Better reliability at normal operating temperature;
- Better efficiency;
- Lower cost per watt.

On the receive side there is little advantage of wide bandgap devices over GaAs:

- Since GaN can withstand higher power, it is possible that the receiver protector can be removed;

- Higher overload resistance, from intentional interferences, friendly interferences, transmitter power return, etc. ;
- Lower “overall” Noise Figure due to absence of Receiver protection limiter.

VIII. INNOVATIVE APPROACH TO MULTIFUNCTIONALITY

In the modern scenarios continues to require higher levels of functionality, performance, and interoperability from on board systems.

The increasing cost of the electronic devices for military applications, especially in the airborne frame (now nearly 50% of the aircraft cost), is pushing the industry to consider the design and development of Integrated systems. These systems will perform the Communication, RADAR and EW functionalities sharing a common set of Active Phased Arrays (APA) and a large number of other building blocks [3].

The level of integration in the conventional federated systems is not sufficient to exploit all the equipments performance because of the difficulties associated with own-platform electromagnetic interference and compatibility.

Moreover the increasing number of antennas produces a negative effect on the platform radar cross section. This problem is particularly relevant to stealth platforms.

The maintenance and operation cost, related to multiple systems, each with its set of spare parts, repair personnel, and operators could be reduced by the development of a single multifunctional system that could simultaneously support multiple functions through a shared set of Active phased array apertures.

The benefit of shared APA apertures are:

- reduced number antennas, thereby, reducing the radar cross section;
- increased potential for future growth without adding new apertures;
- Integrated optimized management of electronic interference and compatibility;
- Flexible HW and SW architectures encouraging the sharing of other building block, and enhancing the platform grow up capabilities;
- Reduction of the life-cycle costs by reducing the number of unique spare parts and lower platform manning by reducing personnel required to operate and maintain equipment;
- Hardware and software architecture are generic, configurable and not function specific wherever possible. This enables the same system resources (e.g., waveform generators, digital beamformers, aperture sub arrays, etc.) to be utilized for several different RF functions, although not necessarily simultaneously.

IX . CONCLUSIONS

ELT is actively participating to the European Consortia aimed to establish an independent European supply chain for the manufacture of GaN HEMT devices and MMICs and, from the system point of view is ready to provide next generation EW (Integrated ESM/ECM) Systems exploiting the potential of SS GaN technology.

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