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The design, development, and development of effective and affordable electronic warfare systems has become a difficult challenge which requires full exploitation of the most advanced technology. Recent history has demonstrated that cost, effectiveness and reliability factors have almost driven on-board self-protection ECM systems to the edge of operational viability. The future must include aggressive and innovative use of new technology to produce penetration aids that are operationally useful and supportable. In the mean time, threat density and sophistication make the basic problem of finding, identifying, and countering all types of threat signals very difficult. The operational choices, as a result, have expanded to include "smart jamming", support jamming in several different forms (stand-off, UAV), expendables (chaff, decoys) and a greater dependence on threat awareness and avoidance. These choices make it imperative to exploit technology to its fulles and in turn they provide an opportunity whereby technologies can be shown to impact the real capability needed operationally. As a result, trends of evolving technologies and visions of what they can mean for the future of electronic warfare are shaping present-day EW research.

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ELECTRONIC WARFARE TECHNOLOGY
TRENDS AND VISIONS
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ELECTRONIC WARFARE TECHNOLOGY -- TRENDS AND VISIONS

Trends of evolving technologies and visions of what they can mean for the future of electronic warfare are shaping present-day EW research. The design, development, and deployment of effective and affordable electronic warfare systems has become a difficult challenge which requires full exploitation of the most advanced technology. Recent history has demonstrated that cost, effectiveness and reliability factors have almost driven on-board self-protection ECM systems to the edge of operational viability. The future must include aggressive and innovative use of new technology to produce penetration aids that are operationally useful and supportable. In the meantime, threat density and sophistication make the basic problem of finding, identifying, and countering all types of threat signals very difficult . The operational choices, as a result, have expanded to include "smart jamming," support jamming in several different forms (standoff, UAV), expendables (chaff, decoys) and a greater dependence on threat awareness and avoidance. These choices make it imperative to exploit technology to its fullest and in turn they provide an opportunity whereby technologies can be shown to impact the real capability needed operationally. This paper will explore some of these new technologies which can and will make a real impact on future EW. First we will look at expendables, an obvious alternative to expensive and complex self-protection ECM systems.

ACTIVE EXPENDABLE DECOYS

Technology has had a significant impact in the development of active RF expendable decoys. Expendable decoys take advantage of spatial separation from the host aircraft, and the transmission of a signal greater in amplitude than that of the aircraft skin return to capture the threat missile and decoy it away from the aircraft. Expendable decoys operate in the "end-game" and in some cases are used to complement the on-board ECM system, not replace it.

Technology has allowed the expendable to move from being threat specific, narrowband devices to wideband, coherent decoys capable of countering a wider range of threats. Technology issues include packaging, isolation, and available output power. Packaging is a key issue because of the small size of existing chaff dispensers (approx. 1"x1"x8"). Isolation is an issue in "straight through" repeater-type decoys of the type currently being investigated under the tri-service "STRAP" program. Unlike transponders or gated (chopped) repeaters, straight through repeaters utilize separate transmit and receive antennas. Sufficient isolation must exist between antennas, or the decoy will self-oscillate. Since chaff-size decoy has a limited amount of physical space, transmit and receive antenna are always in close proximity to each other. Innovative antenna schemes and isolation techniques are being developed to achieve the required isolation.

Transmit power of a decoy must provide sufficient jam-to-signal (J/S) ratios. Past expendable decoys were threat specific because only very narrow band, low power hybrid circuits could be developed. With the development of Gallium Arsenide (GaAs) Monolithic Microwave Integrated Circuit (MMIC) amplifiers, higher output power levels can be achieved within very demanding packaging requirements. The use of MMIC technology in repeater decoys has allowed decoys to respond coherently to a very wide range of threats, therefore decreasing the number of decoys needed, while increasing aircraft survivability. The smaller space that GaAs components take up allow for more space in the decoy body to implement "smart" circuits for programmability, modulations, and threat prioritization to counter the "smart" missile threats of the future.

With the advent of multi-mode missiles, multi-spectral expendable decoys need to be developed. Innovative concepts using state-of-the-art technology will allow an expendable to operate in multiple areas of the electromagnetic spectrum simultaneously. This will provide effective countermeasures against current and future threats. Decreasing cost is necessary for all types of "throw-away" expendables. When this is solved, using maturing technologies, expendable decoys will become an attractive solution to the problem of aircraft survivability.

INFRARED FLARE TECHNOLOGY

A key expendable need, which complements RF countermeasures, is the infrared (IR) flare. New flare technologies are required to effectively counter high performance infrared guided missiles which incorporate sophisticated tracking algorithms. We can no longer rely on the conventional flare to provide protection against such advanced IR missiles.

The first flares were designed to maximize output in the short wavelength region of the IR spectrum (1-3mm), since that was the bandpass in which the earlier IR seekers operated. The goal was to protect as wide a bandpass as possible, so flares were composed of materials which would emit over a wide spectrum (graybody radiators). These flares were ejected from the aircraft as bare pellets, therefore altitude and windstream significantly reduced their output. To compensate for this, the flare was oversized to provide the required J/S in a dynamic environment.

As IR missiles have advanced, the decoy requirements have become more demanding. Flares now are required to produce maximum output at long wavelengths. Since they are typically less efficient at producing IR energy in this spectral region, size has become a problem. The flares are also required to remain closer to the aircraft for a longer time now. Providing a decoy which will more closely match the aircraft's kinematic properties and provide sufficient output has also added to the size requirements of the flare. The "bigger is better" approach enjoyed by the earlier flare designs is no longer valid. Instead, the requirements now are to find materials which can produce longer wavelength radiation in a more efficient manner, determine means for reducing the effect of the windstream on flare output, and providing decoy trajectory to optimize its separation from the aircraft.

Nearly every new flare concept being investigated by the Air Force employs some type of aerodynamic design. In addition to providing a more realistic trajectory, the fact that the flare is stabilized in flight somewhat reduces the quenching effects of the windstream on the burning flare. These configurations also allow for the implementation of other forms of protection from the environment. For example, a shroud can be extended around the burning end of the flare allowing the radiated energy to trail the flare body and reduce the turbulence between the exhaust and the windstream; or, a nozzle of appropriate size can be employed to match the exhaust gas velocity with that of the freestream velocity. Although these techniques show promise for overcoming some of the windstream degradation suffered by a flare (as much as an order of magnitude in a high velocity windstream), much additional work and testing is required to verify effectiveness.

A large variety of compositions have been investigated in an attempt to improve the spectral properties of IR decoys. One approach has been the addition of various materials to the standard flare in order to provide selective emissions in the desired spectral regions or to increase the flare temperature. Other approaches include that of utilizing rocket propellants, since they can be chosen in such a way as to have nearly any desired spectral content, or individual materials which burn at higher temperatures. In most cases, improved spectral characteristics have been demonstrated, but at reduced overall efficiency.

Significant progress has been made in improving IR decoy performance; however, additional work is still required to determine the optimum combination of aerodynamic configuration, shrouds, nozzles and compositions to provide the desired performance.

ON-BOARD DIGITAL-BASED SYSTEMS

New technologies now being evaluated in the laboratory will maintain the viability of onboard systems from a cost, reliability, and performance standpoint. Architectures of self protection systems will be based on digital processing and memory instead of trying to force fit combinations of analog and digital functions. KEY to the success of such new system architectures are the digital RF memories (DRFMs) and digital signal processors (DSPs).

DRFMs have been investigated as retrofits for repeaters since the mid 1970s. Basic problems and trade-offs in developing DRFMs were obtaining desired instantaneous bandwidths and reducing digitization harmonics. Current technology allows ECM system designers to obtain bandwidths well beyond 100MHz and reduce digitization spurs by using up to 6 bits ADCs (analog to digital converters). In the future, based on current research, DRFMs will break the GHz bandwidth barrier with 6 to 8 bit samplers. RF signals can be stored and repeated digitally with precision far exceeding the RF hardware which surrounds the DRFM. This exceptional resolution and potential digital flexibility has presented a new challenge to ECM system researchers, specifically; can DRFMs, and digital hardware in general, replace other functions traditionally accomplished with analog RF hardware.

Digital hardware is now being designed and evaluated by WRDC and AFIT researchers which will perform signal modulation on the DRFM stored signal. Until this breadboard, the modulation function has been performed by RF modulators and signal generators. The potential breakthrough of this Digital Single Side-band Modulator (DSSM) is not only reduction of volume and weight (AFIT is currently designing a CMOS chip which encapsulates the DRFM breadboard design including the DSSM), but the flexibility which will allow system designers to perform much "cleaner" and more complex modulations. The next phase of development being investigated incorporates digital signal processing techniques into the DRFM architecture. Since the DRFM already stores RF signals in digital memory, digital analysis becomes a natural capability. With the DSP capability, the system can perform feature analysis techniques such as auto-correlations which results in an ability to precisely manage the transmitted signal.

The same DRFM breadboard which incorporates the Digital Single Side-band Modulator also includes a two port digital memory architecture for downloading signals to a processor while continuing with traditional DRFM signal flow. Optimizing ECM effectiveness by "tweaking" countermeasures modulations based upon the incoming signal will become a straight-forward function within the system architecture. The digital architecture approach also includes the capability to generate signals without storing an original signal in the memory. A new signal can be introduced into the basic DRFM path either through the dual port memory or through the digital modulator. The DRFM in a sense becomes a very accurate digital synthesizer. The ECM world finally has its combined repeater/transponder capability in a single subsystem! This synthesis capability allows the DRFM to be no longer viewed as a retrofit for repeaters but as a core subsystem for a "Digital Jammer." The concept of the "Digital Jammer" is based upon steerable DRFM channels with a memory design that allows multiple signals to be stored, processed, modified, and/or transmitted simultaneously through different DRFM channels. DSPs will identify features that will allow a technique manager to decide on the best technique and fine tune the output with a DSSM. The channels will be steered by a channelized digital frequency synthesizer, and ECM gating will be performed by advanced trackers which will accurately predict input signal pulses for both lag and lead output pulses. The system will be controlled by an executive that acts as a resource manager, assigning input and output channels and tracker channels, directing DSP analysis, setting the synthesizer frequencies, and initializing modulation signals. The entire system will handle multiple simultaneous input and output signals as well as time sharing and multiplexing resources in both a power and time optimal fashion.

SOFTWARE CONSIDERATIONS

The versatility of digital circuitry is enhanced or limited by programmability, hence the current revolutions in software as engineers try to address the problems of software created by obsolete development techniques or "artistry." The buzz-words of software technology today; maintainability, reusability, extraction, separate compilation, etc; all address the cost effectiveness of programmable systems. As systems become more complex, software engineering becomes all the more critical for maintaining a reasonable level of cost effectiveness. Ada is the most advanced program language from a software engineering perspective. While problems still "appear" to exist with this DOD mandated language, the EW developers who have spent the initial investment in changing to Ada as the desired HOL (Higher Order Language) have found that the problems are relatively minor compared to the long-term cost savings.

The EW community has been relatively slow in their conversion to Ada as the prime HOL. Part of this slow conversion is due to the concern that HOLs may not be able to handle the high performance, real-time, constraints of EW. EW system developers in the past have had neither the need for nor the trust in the capability of high level digital systems. Recently, the complexity and flexibility of the threat have forced the EW system houses toward large complex software driven systems to counter the threat numbers and capabilities. The effect has been investigations in AI (Artificial Intelligence), parallel and distributed processing concepts (ranging from pipelining and array processors to neural networks) and software engineering techniques. One of the more interesting and less predicted matches in advanced processing has been Ada-implemented AI techniques. Much in the way of expert system tools and knowledge based systems are being implemented in Ada to meet the DOD mandate. With the advent of the knowledge based system technology, EW designers have found advanced decision making capability for classification and resource management. With Ada implementations of these decision making systems, some of the embedded system reliability and maintainability issues are solved.

ACOUSTIC CHARGE TRANSPORT

As an alternative or an adjunct to digital processing technology, Acoustic Charge Transport (ACT) technology shows great potential for the EW field. It was first demonstrated in 1982 at the University of Illinois and devices are currently under development and production at Electronic Decisions, Inc. Additionally, many other firms are now studying possible applications of ACT technology.

ACT fills the gaps between MMIC "front ends" and VHSIC command/control units for signal processing. Devices are being created on GaAs allowing for direct integration with semiconductors. This means signals can be sampled, filtered and digitally changed/analyzed on the same monolithic GaAs implementation. Most peripheral circuitry can now b located on the same medium for a complete circuit on one chip.

ACT devices offer signal processing capabilities with unparalleled bandwidth, high dynamic range and linearity. In addition, these devices are simple and much smaller than their counterparts and are much more reliable. The basic function of an ACT is that of a delay line. There is a basic unit delay (usually in the range of a few seconds) between the source sampling contact and drain contact, where the delayed output exits the device. When hold electrodes are applied to the structure, an additional delay can be applied to the signal thus creating an analog memory. An obvious benefit of ACT is the ability to store signals without resorting to analog-to-digital conversion. By adding a series of non-destructive sensor outputs to the surface of the device and attenuating the sampled signals, then summing the samples, a tapped delay line can be realized. Tapped delay lines function very well as chirp filters and correlators. Digitally programmable tapped delay lines (vector processors) for correlation, convolution, matched filtering and transformation can be obtained by making the fixed attenuators variable and controlling them digitally. ACT devices can also be cascaded or paralleled: the result of which will give double the signal length or double the bandwidth/sampling rate, respectively.

When ACT memories are compared to DRFMs, ACT devices provide: higher spectral purity upon reconstruction of signal; the speed and simplicity of analog devices; lower volume, weight and power requirements; and reduced additional circuitry. ACT based devices will not, however, make DRFMs obsolete. One benefit of DRFMs over ACTs is that ACT devices have limited signal length and hold times. For some threats, DRFMs' relatively unlimited signal length and delay times make them the obvious choice. But, for many other threats, ACT devices stand as the clear choice based upon the total picture.

SOLID STATE ARRAY TRANSMITTERS

In considering the performance and especially the reliability of on-board countermeasures systems, the transmitter has historically been an area of concern. Solid State Monolithic Microwave Integrated Circuit (MMIC) amplifiers in combination with array antennas offer an attractive alternative to the current TWT/low gain antenna configuration for much improved EW system reliability. Reliability will be increased by at least an order of magnitude by: (1) eliminating the failure-prone TWT and its associated high voltage power supply, and (2) using distributed amplifiers which results in continued operation with minimal change in performance (graceful degradation) of the ECM transmitter if an amplifier fails. The transmitters can be designed to be modular and maintainable. The effective radiated power produced by the transmitter can be customized to the platform by stacking identical linear array modules to achieve the desired power. Modularity also promotes ease of maintenance. Any individual linear array module can be readily removed for maintenance without affecting the other modules. Solid state transmitters can be designed to cover 2 to 20 Gigahertz in two bands for use in both standoff and self protection jamming applications. They will provide high reliability, selective jamming of multiple threats, reduced volume, low weight and lower cost. An area of continuing development is that of high current, low voltage power supplies that must be demonstrated before a high power solid state array transmitter becomes an operational reality. Distributed power supplies will contribute to high reliability and the graceful degradation inherent in array transmitters.

In summary, there are many new exciting technologies which are now being applied to EW problems. As a result, entirely new approaches to operational countermeasure capabilities will become available with improved cost, complexity and reliability. The areas discussed in this paper are all being researched within the Active Electronic Countermeasures Branch of WRDC. Many of the capabilities mentioned have been demonstrated in the Laboratories of the Branch. These and many other ideas and technologies form a significant area of research that, we feel, will provide the breakthroughs needed to demonstrate cost effective countermeasures capabilities.