Waveform Diversity and Compatibility

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Abstract

Waveform diversity in multistatic radar systems can enhance distributed radar system performance. Dynamically changing the electromagnetic emanations of radar and communications systems however poses an electromagnetic compatibility (EMC) challenge. Data are provided illustrating how waveform diversity improves multistatic radar system performance. An approach for maintaining EMC in a dynamically changing environment is also provided.

1. Introduction

Sensor performance may be enhanced by selecting algorithms adaptively as the environment changes. It has been shown [1–7], that if an airborne radar system uses prior knowledge concerning certain features of the earth (e.g. land-sea interfaces) intelligently, then performance in the filtering, detection and tracking stages of a radar processing chain improves dramatically. As an example, the performance of an intelligent radar can be imporved if the characteristics and location of electromagnetic interference, mountainous terrain, and weather conditions are known. The Sensors Directorate of the USAF Research Laboratory conducted and sponsored research and development in the use of prior knowledge for enhancing radar performance, as did the Defense Advanced Research Project Agency (DARPA) under the Knowledge Aided Sensor Signal Processing Expert Reasoning (KASSPER) program.

One design of an intelligent radar system that processes information from the filter, detector, and tracker stages of a surveillance radar, investigated by the USAF and under the KASSPER program, was specifically designed for an Airborne Intelligent Radar System (AIRS). This architecture design leveraged advancements pursued by the World Wide Web Consortium (W3C) and DARPA Agent Markup Language (DAML) program for constructing the next generation Internet. Futuristic advanced intelligent radar systems will cooperatively perform signal and data processing within and between sensors and communications systems while utilizing waveform diversity and performing multi-sensor processing, for reconnaissance, surveillance, imaging and communications within the same radar system. A description of AIRS is described in detail in the literature [6, 8].

There are other efforts concerned with dynamically controlling the emission and reception of radio frequencies in addition to AIRS, for example, the XG (neXt Generation Communications) program sponsored by DARPA. The XG program developed an architecture that will open up the spectrum for more efficient use by first sensing and then using portions of the spectrum for XG radio transmissions adaptively.

The goals of the XG program are: 1. Demonstrate through technological innovation the ability to utilize available (unused, as opposed to unallocated) spectrum more efficiently, and 2. Develop the underlying architecture and framework required to enable the practical application of such technological advances [9]. Another effort related to communications, that has similar goals as the XG program, is the Cognitive Radio [10]. Its objectives are to efficiently utilize the radio frequency (RF) spectrum and to provide reliable communications at all times. A general overview and projections of the Cognitive Radio in our society can be found in [11].

The US Air Force (USAF) was one of the original investigators in applying knowledge based processing to radar signal processing. A current initiative is the Sensors as Robots (SaR) program. A sensor system's performance can be enhanced by adapting sensor algorithms as the environment changes. It has been shown that an airborne radar system's performance can be improved by exploiting knowledge of certain features of the earth (e.g. land/sea interfaces) and its surroundings. Portions of SaR to date have been applied to an airborne radar surveillance system flying a repetitive route accumulating data and knowledge to be used during the next sortie. However, today's adversaries are not traveling in truck convoys, flying aircraft in formation, or traveling the desert in tanks. They cannot easily be detected and tracked with stand-off airborne sensors such as AWACS or JSTARS. Today's adversaries are embedded in urban environments traveling in ordinary vehicles, dressed as civilians, and carrying small weapons and bombs. Large surveillance platforms cannot easily detect weapon carrying individuals driving

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vehicles that are kilometers away. Nor can they detect remotely located weapon caches housed in dense urban areas. To meet these requirements, numerous organizations are investigating unmanned air vehicles (UAVs) with different sensors which can be deployed in urban and rural regions to detect and track various targets. These UAVs may operate either on their own, in conjunction with surveillance platforms, or with minimum human intervention. One of many scenarios may be to deploy numerous UAVs with smart receivers in conjunction with a controllable strong radiator to illuminate the area of interest and have the UAVs jointly process their received signals. For multistatic radar it has been shown [12] that performance is dependent on both waveform and geometry, i.e. the position of the target test cell and the positions of the transmitters and receivers. We will provide an overview of the multistatic ambiguity function (MAF) and demonstrate how multistatic performance measures can be improved through waveform diversity e.g. changing the pulse repetition frequency (PRF). In so doing we are beginning to develop a rule set for intelligent pre-detection multistatic data fusion.

Waveform diversity for radar and communication systems however may cause EM fratricide and new techniques are required if SaR, XG and Cognitive Radios are to be deployed successively. In Section 2 an overview of Multistatic Ambiguity Function (MAF) is presented and results provided showing how waveform diversity can improve radar performance. Section 3 describes the paradigm shift that will be required to accommodate waveform diversity equipments in our military systems. Section 4 provides our summary and conclusions.

2. Multistatic Ambiguity Function

The ambiguity function is a commonly used measure for the analysis of radar systems. In the case of monostatic radar systems, the ambiguity function was shown to play an important role in quantifying different system performances. Recently, the concept of the ambiguity function was extended to the case of multistatic radar systems [12-14] where the multistatic ambiguity function was used for assessing waveform selection [12-13] and radar fusion strategies [14].

In particular, in [12] the authors studied the bistatic ambiguity function and demonstrated how system geometry and waveform selection determine the shape features of the ambiguity function such as the area under the main lobe and location of the sidelobes. In [13] the authors considered the 2-D system geometries with single transmitter and multiple receivers and studied the system performances for different waveforms. It was demonstrated that the system resolution is directly affected by the waveform. To illustrate this observation let us consider the system geometry with a single receiver and four receivers. Figures 1 and 2 show the multistatic ambiguity function for two different waveforms (Barker 5 and Barker 13, respectively) with all other assumptions and system parameters (such as system geometry, weighting coefficients, pulse width, number of pulses and total waveform duration) being the same (see [13] for more details).

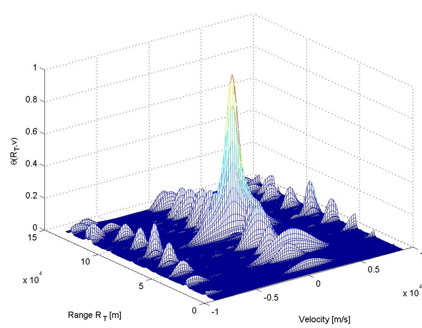

Figure 1. Multistatic ambiguity function (Barker 5 waveform)

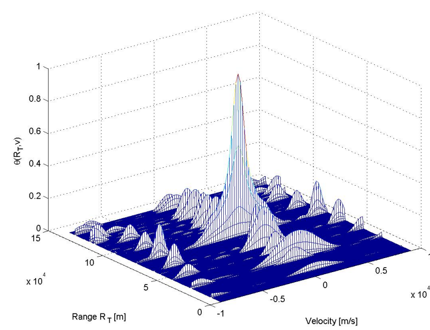

Figure 2. Multistatic ambiguity function (Barker 13 waveform)

To illustrate the differences in resolution, the multistatic ambiguity functions for both waveforms (3-dB main lobe contours) are shown in Figures 3 and 4.

As can be seen and expected, the Barker 13 waveform has significantly better range resolution: the 3dB width for the Barker 5 is approximately 1040m, while in the case of Barker 13 waveform the width is approximately 480m, a reduction of 54%. The topic of our latest research efforts is how waveform parameters such as pulse width and number of pulses affect the shape of the ambiguity function in 3-D geometries with a single transmitter and multiple receivers. Some preliminary results are shown in Figures 5 and 6 that show multistatic ambiguity function for 5-pulse and 3-pulse LFM waveform, respectively, and for the same system geometry, weighing of the receivers, pulse width and total waveform duration.

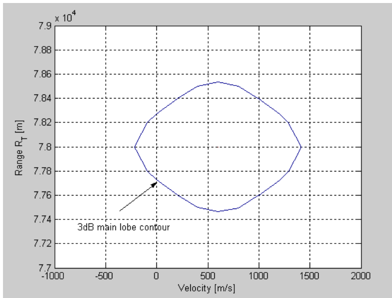

Figure 3. Barker 5 ambiguity function (3dB contour plot - main lobe)

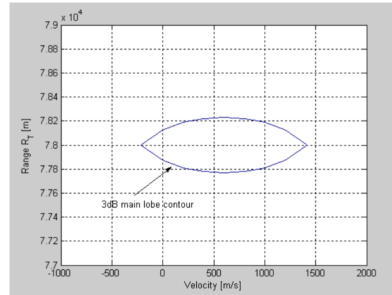

Figure 4. Barker 13 ambiguity function (3dB contour plot – main lobe)

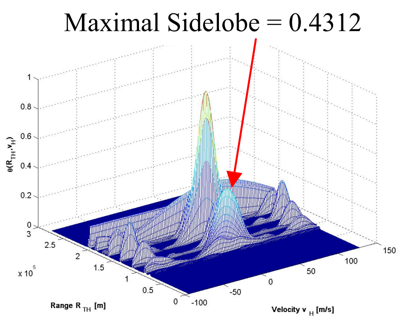

Figure 5. Multistatic ambiguity function for 5-pulse LFM

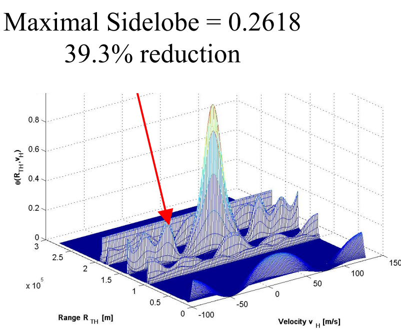

Figure 6. Multistatic ambiguity function for 3-pulse LFM

As can be seen, in this case the position and height of the sidelobes is significantly affected. For example in the case of 5-pulse LFM the height of the maximal sidelobe is 0.4312 (see Figure 5) in the region of interest. This result can be improved by switching to a 3-pulse LFM where this height is 0.2618 (39.3% reduction).

3. EMC Paradigm Shift

Waveform diversity technology allows one or more sensors to change operating parameters automatically, e.g. frequency, gain pattern, pulse repetition frequency (PRF). A system of sensors can then adapt operations to meet the stressing and changing environments that military systems must face. This will meet the goal of moving sensors any place in the world to defend against different missile systems and their potential deployments, even those systems that do not currently exist. The concept of waveform diversity is growing in popularity within the signal processing community. In the not too distant future sensor and communication devices will have the capability to receive information from multiple sources and to decide which signal modulation and antenna parameters need to change in order to perform their functions most effectively. They will also seamlessly coordinate changes with an intelligent coordinator that approves requested changes and/or negotiates another change that allows better performance, and yet maintains EM compatibility within and between nearby platforms. This is a problem since there are multiple sensor and communication systems onboard platforms.

Military weapon systems are engineered to prevent such phenomena between hardware located in close proximity. The military has standards for describing how to build and test hardware for EMC, and how to test weapon system platforms for EMC, e.g. Military Standards 461E and 464. The Department of Defense has also developed EMC prediction tools to assess the EMC of its weapon systems. These tools were developed during the 1970s and 1980s and have been enhanced and used since then. They were developed according to military standards to assure proper systems testing was performed, because most of the systems developed then were deployed in space where fixing EMI problems is not practical. Using software tools to perform EM measurements in the 1970s was a major paradigm shift for the EMC community.

Just as we needed a change by using software tools to assess a system's EMC in the 1970s, we now need to rethink how to build complex systems that employ waveform diversity and some of the proposed XG and Cognitive Radio spectrum management concepts. Whereas in the 1970s we required software tools to predict where to hone our measurements, we now need to use software to help determine when EMI may occur in real-time, and manage the EM spectrum while the platform increases its EM performance. This performance gain is not related to just one system onboard the platform, but to a system performance measure of the total platform, where the platform may contain communications, navigation, radar sensors, etc. The EMC tools used today assess the performance of an individual stovepipe system, e.g. the increase in bit error rate of communications equipment and the decrease in probability of detection of a radar. The predictions made by these performance measures are usually related to the signal to noise plus interference ratios computed for each transmitter coupled to each receiver. The tools also compute the sum or integration of all transmitters' coupling into a receiver(s) along with a hypothesized EM spectrum, to represent the environment, and to predict an integrated or total EM ratio which can be related to a receiver's performance. This method identifies the performance of each receiver, but it does not alert us to the degradation of the total weapon system's performance. In addition, each computation is performed for a fixed set of operating conditions for each transmitter and receiver of EM energy. This approach is acceptable when analyzing a weapon system with conventional equipment, where each system's performance is assessed independent of all others. However, this is not acceptable for a weapon system or platform with a global performance requirement(s) or when the waveform parameters of one or more of its systems are changing in real-time.

4. Summary and Conclusions

We have provided an overview of waveform diversity and how they are being studied for communications and radar systems. The deployment of these systems within military platforms has a great potential of causing EM fratricide. Semantic Web technologies can help us manage the EM spectrum within military platforms. However, we will need a paradigm shift in how we develop these intelligent platform systems that can manage waveform diversity equipments when deployed with current EM equipments on the same or nearby platforms. The EMC area has a new challenge in the integration of waveform diversity equipments for the military and commercial worlds.

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