

Jamming Techniques 2.0

Charles Brooks
SRC Inc.
Patuxent River, MD
cbrooks@srcinc.com

David Haber
Collins Aerospace
Sterling, VA
david.haber@collins.com

Patrick Merlet
Parsons Corporation
Orlando, FL
patrick.merlet@parsons.com

ABSTRACT

IEEE Std 1278.1 (Institute of Electrical and Electronics Engineers (IEEE) Standard for Distributed Interactive Simulation—Application Protocols) defines a protocol that is used, in part, to simulate radars, jammers, and electronic warfare. The protocol includes a Jamming Technique field that represents the jamming technique being employed by a jammer. The associated list of jamming techniques is hierarchical and enumerated in SISO-REF-010 (Simulation Interoperability Standards Organization (SISO) Reference for Enumerations for Simulation Interoperability). Currently the 134 jamming techniques listed in SISO-REF-010 provide no information other than name, enumeration, and location in the hierarchy. This is not enough information to ensure common understanding among electronic warfare subject matter experts and simulation developers to support interoperability, fair fight, and good training. This paper describes an effort to provide definitions for the jamming techniques, address issues with the hierarchy, and provide additional jamming interaction protocol data that will support improved simulation and training. The results of this effort are proposed changes to SISO-REF-010 and IEEE Std 1278.1.

The SISO-REF-010 enumeration changes will a) deprecate the current jamming technique enumerations, b) replace them with an improved list and hierarchy, and c) provide definitions for valid jamming techniques.

The IEEE Std 1278.1 protocol changes will add the representation of a) multiple jamming techniques, b) the jammer architecture, and c) jamming attributes.

Together these proposed changes enable a more accurate, advanced, flexible and higher fidelity representation of simulated radar jamming interactions while improving the support for multiple levels of fidelity and thus increased interoperability. The additional protocol information also provides a jamming modeling simplification that results in more uniform and efficient processing of distributed electronic warfare simulation interactions. The proposals will hopefully encourage the international simulation community to review the changes and provide feedback and collaboration that will further improve electronic warfare simulation.

ABOUT THE AUTHORS

Charles Brooks has 29 years of experience in Electronic Warfare (EW), Modeling & Simulation (M&S), and Systems Engineering for EW and M&S. Mr. Brooks is currently an Engineering Manager for SRC, Inc., a not-for-profit R&D organization that supports the defense and intelligence industries. Mr. Brooks has experience with operational EW deployments, threat analysis, and the development of concept models and simulation architectures for Radar, Jammer, Comms, and EW environment simulation across a broad spectrum of applications. As an EW engineer Mr. Brooks designed and constructed a laboratory jammer for Test & Evaluation (T&E) of digital communication systems for the Air Combat Environment Test & Evaluation Facility (ACETEF) and in 2010 organized and chaired an Electronic Attack M&S Conference at Naval Air Station Patuxent River. Mr. Brooks is a member of the American Institute of Aeronautics and Astronautics (AIAA), the National Defense Industrial Association (NDIA), the Association of Old Crows, and the Simulation Interoperability Standards Organization (SISO).

David Haber is a Principal Systems Engineer at Collins Aerospace. Mr. Haber is responsible for the simulation architectures of avionics, electronic warfare, communications, navigation, weapons, and radar sensors. Mr. Haber has 32 years of experience working for multiple companies in the simulation industry. Mr. Haber's experience includes software engineering, systems engineering, and engineering team leadership in military aviation training systems including new simulators and major upgrades. Mr. Haber helped bring the B-1 training system into Combat Air Force Distributed Mission Operations (CAF DMO), including CAF DMO standards improvements of electronic warfare fidelity. Mr. Haber holds a Bachelor of Electrical Engineering degree from Johns Hopkins University and a Master of Engineering in Systems Engineering degree from Stevens Institute of Technology. Mr. Haber is a member of the Association of Old Crows, the Simulation Interoperability Standards Organization (SISO), the International Council on Systems Engineering (INCOSE), and the National Defense Industrial Association (NDIA).

Patrick Merlet is a Project Manager with Parsons Corporation and holds an M.S. in Computer Science from the University of Central Florida. Mr. Merlet has a total of 38 years of experience in systems and software engineering and 16 years of experience in simulation interoperability standards. Mr. Merlet is a Standards Lead on the United States Air Force Combat Air Force Distributed Mission Operations (CAF DMO) Operations & Integration (O&I) Program. Mr. Merlet is also the Secretary of the Simulation Interoperability Standards Organization (SISO) Distributed Interactive Simulation / Real-time Platform Reference Federation Object Model (DIS / RPR FOM) Product Support Group (PSG).

Jamming Techniques 2.0

Charles Brooks
SRC Inc.
Patuxent River, MD
cbrooks@srcinc.com

David Haber
Collins Aerospace
Sterling, VA
david.haber@collins.com

Patrick Merlet
Parsons Corporation
Orlando, FL
patrick.merlet@parsons.com

INTRODUCTION

This paper describes issues related to jamming techniques and their use in distributed electronic warfare simulation, our approach to solving the issues, the resulting proposed changes, and finally our conclusions and plans.

Problem Statement

IEEE Std 1278.1 (Institute of Electrical and Electronics Engineers (IEEE) Standard for Distributed Interactive Simulation—Application Protocols) defines a protocol that is used, in part, to simulate radars, jammers, and electronic warfare. The protocol includes a Jamming Technique field in the Electromagnetic Emission (EE) Protocol Data Unit (PDU) that represents the jamming technique being employed by a jammer in a jamming beam signal. The associated list of jamming techniques is hierarchical and enumerated in SISO-REF-010 (Simulation Interoperability Standards Organization (SISO) Reference for Enumerations for Simulation Interoperability). Currently the 134 jamming techniques listed in SISO-REF-010 provide no information other than name, enumeration, and location in the hierarchy. This is not enough information to ensure common understanding among electronic warfare subject matter experts and simulation developers to support interoperability, fair fight, and good training. This effort began with the single goal of addressing this issue by adding jamming technique definitions. As the effort progressed, the scope increased to address additional related issues that were uncovered.

A close examination of the current jamming technique enumeration hierarchy reveals that it often does not support jamming technique “promotion” as described by IEEE Std 1278.1 in Section 5.7.3.4, Receipt of the EE PDU, and in Section 5.7.3.8, Jamming. Promotion, or rollup, is when a radar model receives a detailed jamming technique enumeration that is beyond its capability to process and rolls it up in the hierarchy to the most specific jamming technique that it supports. A good jamming technique enumeration hierarchy that properly supports rollup is necessary to enable interoperability between disparate simulation and training systems that operate at different levels of fidelity.

Finally, in addition to the problems with the jamming techniques and hierarchy, there is insufficient data in the IEEE Std 1278.1 protocol to support complex jamming susceptibility decisions in the radar model.

Objectives

The purpose of this paper is to describe the effort undertaken to accomplish these three objectives:

- Provide a common understanding of simulated radar jamming techniques
- Correct problems with the current simulation jamming technique hierarchy
- Improve the fidelity of simulated jamming interactions

IEEE Std 1278.1 Section 1.6.2, Basic architecture concepts, defines the distributed interactive simulation concept where a given simulation is responsible for modeling the results of actions within the simulation and sending messages to other simulations, as necessary, to inform them of any observable actions. All simulations are responsible for interpreting and responding to messages of interest from other simulations. Following this basic distributed interactive

simulation concept, this effort only addresses the transmitted simulated jamming messages and protocol data. Jamming effectiveness against a simulated radar that is being jammed is the responsibility of the receiving radar simulation.

This effort falls under the auspices of the Simulation Interoperability Standards Organization (SISO) Distributed Interactive Simulation / Real-time Platform Reference Federation Object Model (DIS / RPR FOM) Product Support Group (PSG) and the SISO Standards Activity Committee Special Working Group Reference for Enumerations for Simulation (SAC SWG Enumerations). IEEE Std 1278.1 is sponsored by the SISO Standards Activity Committee. Proposed changes resulting from this effort are being coordinated with these organizations.

JAMMING TECHNIQUE REDESIGN

Overview

While this effort started with the simple goal of providing jamming technique definitions, it grew to include a complete redesign of the jamming technique enumeration hierarchy. The definitions provide a common understanding of the jamming techniques and the redesign solves issues with the hierarchy. Proposed changes to the SISO-REF-010 jamming techniques deprecate entries that are not valid jamming techniques, provide definitions for valid jamming techniques, and place the valid techniques into a new enumeration hierarchy to allow correct jamming technique rollup in accordance with IEEE Std 1278.1.

Issues with the Jamming Technique Hierarchy

IEEE Std 1278.1 Section 5.7.3.4, Receipt of the EE PDU, and Section 5.7.3.8, Jamming, defines promotion, or rollup, as a requirement to model jamming at the highest fidelity available in the receiving radar model. This rollup allows a simplified radar simulation to receive a detailed jamming technique and roll it up to a more simplified level, while maintaining the same jamming intent. The rollup uses a jamming technique enumeration of less detail within the same section of the enumeration hierarchy. For example, if a jamming technique of Automatic Spot Noise (1.75.5) is received by a radar simulation that does not support this level of jamming fidelity, the jamming technique can be rolled up to Spot Noise (1.75). Both Automatic Spot Noise and Spot Noise are range obscuration techniques, providing the same effects at different fidelity levels.

The current jamming technique hierarchy has some enumerations that do not rollup correctly. For example, if a jamming technique of Skirt Frequency (1.75.25) is received by a radar simulation that does not support this level of jamming fidelity, the radar simulation can rollup the jamming technique to Spot Noise (1.75), similar to the example above. However, Skirt Frequency is an angle deception technique, and Spot Noise is a range obscuration technique. This rollup would result in an incorrect jamming effect when simulations of different fidelities are interacting in a simulation exercise. In a training exercise this could result in fair fight issues and negative training. This is because Skirt Frequency (1.75.25) is in the wrong place in the jamming technique hierarchy, as are many other jamming techniques in the current hierarchy.

There are other issues with the current jamming technique list and hierarchy, including jamming techniques that are not valid techniques, and there are many fixed-combination techniques that are better represented in a different, more flexible manner.

New and Improved Jamming Technique Hierarchy

The current jamming technique hierarchy is based on a four-part enumeration comprised of Kind, Category, Subcategory, and Specific. The hierarchy is mostly self-explanatory with Kind having values of Noise (1), Deception (2), Deception and Noise (3), and Special (4).

The new proposed jamming technique hierarchy is based on a five-part enumeration comprised of Type (the type of jamming), Intent (the intent of the jamming), Waveform (the type of waveform), Modulation (the type of modulation), and Specific. The two primary types of jamming are Obscuration (10) and Deception (20), and Special (30) is maintained to support its use as a simulation override or electronic warfare simulation management function. The next three components of intent, waveform, and modulation provide a much more powerful representation mechanism

based on independent jamming technique characteristics. The new jamming technique hierarchy includes all valid jamming techniques from the old hierarchy but organized in a manner that supports rollup while maintaining the jamming type and intent and without introducing errors. The enumeration values for the new jamming technique hierarchy are shown below in Figure 1:

Type	Intent	Waveform	Modulation	Specific
10 Obscuration 20 Deception 30 Special	0 Not Specified 10 Range 20 Velocity 30 Angle 40 Multiple False Targets (MFT)	0 Not Specified 10 Noise 20 Pulse 30 Continuous Wave (CW)	0 Not Specified 10 Frequency 20 Phase 30 Time 40 Amplitude 50 Polarization 60 Not Modulated	0 Not Specified >0 Varies

Figure 1 – New 5-Part Jamming Technique Enumeration Values

For the Modulation enumeration value 10, Frequency represents the carrier frequency. For Specific, values greater than zero (e.g., 10, 20) are used to enumerate jamming techniques that are not otherwise already uniquely identified. The enumeration values are spaced apart as shown to allow room for future insertions as necessary.

Figure 2 below provides a graphical depiction of selected portions of the new jamming technique hierarchy. This example illustrates the structure of the new hierarchy and how the five-part enumeration supports several jamming techniques at various levels of fidelity.

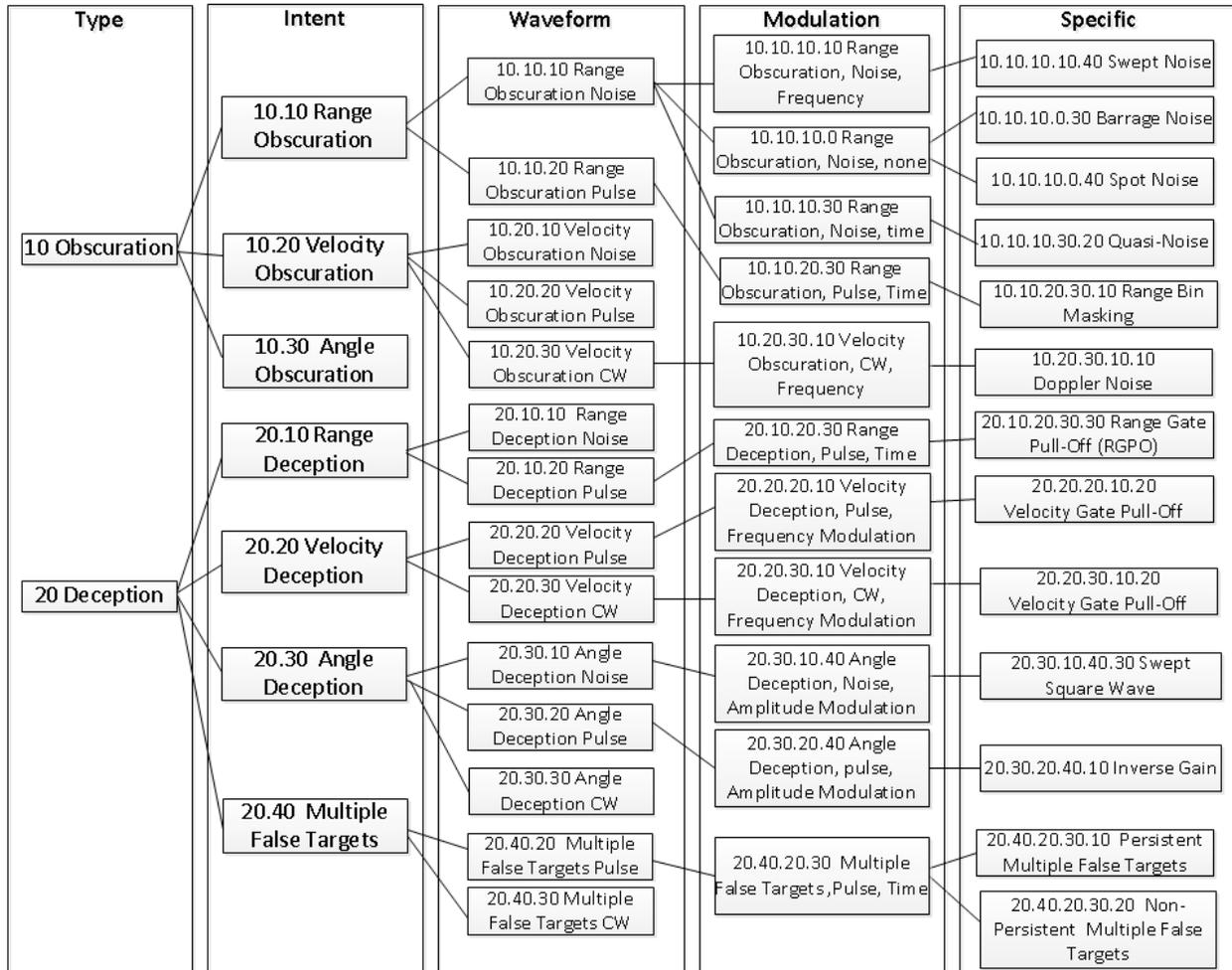


Figure 2 - Selected Portions of the New Jamming Technique Hierarchy

The new jamming technique hierarchy supports two radar model jamming decisions:

1. Jamming susceptibility
2. Jamming effect

A radar model being jammed can use the fundamental parameters (e.g., frequency, effective radiated power) in the Electromagnetic Emission PDU along with the jamming technique enumeration to make the jamming susceptibility decision, and if jammed, the radar model can generate display effects, tracking error effects, and/or other effects as appropriate.

As shown in Figure 2 above, there are multiple enumerations for some jamming techniques. For example, Velocity Gate Pull-Off (20.20.20.10.20 and 20.20.30.10.20) is a frequency modulation technique that can be applied to multiple waveforms. In this example, Velocity Gate Pull-Off modulation is being applied to a continuous wave waveform as well as a pulse waveform. Having unique specific enumerations for these types of jamming techniques aids in the jamming susceptibility decision as well as determining jamming effects.

The new hierarchy provides better support for the concept of rollup, as previously mentioned. Jamming technique rollup allows a simplified radar simulation to receive a detailed/specific jamming technique and roll it up to a more simplified/abstract level while maintaining the same jamming type and intent. For example, if a radar simulation

receives an Angle Deception, Pulse Waveform, Amplitude Modulation, Inverse Gain (20.30.20.40.10) jamming technique, the radar model can rollup this enumeration to a more abstract jamming technique as required. If the radar model does not have the fidelity to process the detailed jamming technique, it can be rolled up to the level of fidelity understood by the radar model to determine jamming susceptibility and jamming effects. In this case, if the radar model can only process a jamming technique down to the waveform level, then it could rollup this technique to Angle Deception, Pulse Waveform (20.30.20) and process the jamming technique as an angle deception on pulse waveform technique.

For another example, consider a jamming technique of angle deception using noise waveform and amplitude modulation: Angle Deception, Noise Waveform, Amplitude Modulation (20.30.10.40). A very simple radar model can rollup this jamming technique further to determine jamming susceptibility and jamming effects, without losing the jamming intent. Rolling this jamming technique up to the waveform level yields angle deception using a noise waveform: Angle Deception, Noise Waveform (20.30.10).

Deprecated Jamming Techniques

An analysis of each of the current SISO-REF-010 jamming techniques was conducted to provide a definition from an open, exportable, authoritative source and to determine the appropriate position in the new jamming technique hierarchy. All of the valid current jamming techniques are being placed in the new hierarchy, with cross-reference information provided. This analysis left some of the current jamming techniques without a definition from an authoritative source, and some which were deemed to be invalid jamming techniques; these are all being recommended for deprecation, with rationale and any additional information provided as appropriate. In addition, jamming technique enumerations that represent combinations of jamming techniques are being recommended for deprecation because combinations of jamming techniques are being addressed in a different manner in proposed changes for the Electromagnetic Emission PDU (described later).

Below are several examples of jamming techniques being recommended for deprecation and the supporting rationale:

- Amplitude Modulation Noise (1.5) – Authoritative definition not found
- Click (1.10.5) – Authoritative definition not found
- Down Link (2.60) – This is an exploitation point and not a specific technique, this technique is being recommended for deprecation and replacement by a jamming attribute bit in the Electromagnetic Emission PDU (described later)
- Terrain Bounce (2.10.45) – This is a beam geometry exploitation point and not a specific technique; this technique is being recommended for deprecation and replacement by a jamming attribute bit in the Electromagnetic Emission PDU (described later)
- Combination Techniques – All combination jamming technique enumerations, e.g., Inverse Gain and Spot Noise (3.20.10), are being recommended for deprecation and replacement by a new method of representing multiple jamming techniques in the Electromagnetic Emission PDU (described later)

Jamming Technique Definitions

Several representative examples of authoritative jamming technique definitions are shown below in Table 1. The jamming technique definitions provide a common understanding of each jamming technique. Providing authoritative definitions with the jamming techniques in SISO-REF-010 will resolve ambiguities and promote a common understanding for all users of the jamming techniques for electronic warfare simulation. All references are limited to open exportable authoritative sources. The SISO-REF-010 proposed changes will include authoritative definitions for all jamming techniques. Full reference details are provided at the end of this paper.

Table 1 – Example Jamming Technique Definitions with Source References

Jamming Technique	Definition	Reference
Barrage Noise	Barrage Noise signifies the spreading of noise-like jamming energy over a wide frequency band such that many victim radars can be jammed over their whole agile bandwidth simultaneously. Bandwidth on the order of 100 MHz to an octave is thought of as being barrage.	Applied ECM Volume 1, page 464
Doppler Noise	This is a self-screening Electronic Counter Measures (ECM) technique that generates an output noise signal by randomly varying the serrodyne saw-tooth frequency, producing a band of noise about the victim radar carrier frequency that will keep a velocity tracking radar from detecting the true carrier signal.	Applied ECM Volume 1, page 916
Quasi-Noise	A controlled, noise-like, pulse pattern repeated in synchronism with the victim radar pulse repetition frequency.	Electronic Warfare and Radar Systems Engineering Handbook, page 4-13.4
Range Bin Masking	In Range Bin Masking, rather than using noise to mask the echo signal, copies of the radar pulse are transmitted by the jammer before and after the received radar pulse. This will produce an effect on the radar such that targets appear in a number of adjacent range bins, thereby masking the location of the true echo signal.	Investigation of a Novel Software Based Laboratory Jammer Architecture, page 24
Swept Square Wave	Swept Square Wave is a self-screening ECM technique that is produced by amplitude modulating the output signal of an ECM set with a square or rectangular wave that sweeps in frequency through the expected scan frequency range of a conical-scan tracking radar for the purpose of producing angle tracking errors. It is usually restricted to Scan on Receive Only (SORO) type radars.	Applied ECM Volume 1, page 898
Constant False Alarm Rate	Constant False Alarm Rate jamming is the introduction of synthetic clutter into the radar's signal processor to suppress target returns.	Electronic Warfare in the Information Age, page 19

ELECTROMAGNETIC EMISSION PDU CHANGES

Overview

Below are the proposed changes to the IEEE Std 1278.1 Electromagnetic Emission PDU to provide for better jamming fidelity and combination jamming techniques. The recommendation includes two new fields to be added: a Jammer Architecture field and a Jamming Attributes field. The Jamming Technique field is recommended to be changed from a single value field to an array of jamming techniques so that more than one jamming technique can be associated with an Electromagnetic Emission beam.

These proposed changes are incorporated below in Figure 3, which is a working draft of the next (third) generation (Gen3) of the Electromagnetic Emission PDU being developed for the next version of IEEE Std 1278.1.

EE PDU

HDR	Proto Ver	Compat Ver	Exercise ID	PDU Type	PDU Status	HDR Len	PDU Length	
	Timestamp							
BODY	Emitting Entity ID						Sequence Number	
	Emitter System							
	Location with respect to entity							
	Padding						Num Extension Records (N)	
Extension Record 1	Record Type = 3503 (EE Beam extension record)				Record Length		Beam Num	Beam Status
	Beam Func	Padding	Beam Parameter Index					
	Fundamental Parameter Data							
	Beam Data							
					High Density	Padding	Number of Targets	
	Array of Track/Jam Data							
	Jammer Architecture		Jamming Attributes		Padding		Number of Techniques	
	Array of Jamming Techniques							
	Extension Record 2							
	...							
Extension Record N								

Figure 3 – Working Draft of the IEEE Std 1278.1 Gen3 Electromagnetic Emission PDU

Figure 3 above shows the PDU header at the top, followed by the fixed body of the PDU, followed by a variable number of extension records. Figure 3 illustrates the inclusion of a beam extension record. Within the beam extension record is the Jammer Architecture Field, the Jamming Attributes field, and an Array of Jamming Techniques, which is preceded by a Number of Jamming Techniques field. Each of these Electromagnetic Emission PDU proposed changes is described below.

NOTE: The proposed Electromagnetic Emission PDU fields presented in this paper are provided in a manner similar to how they would appear in IEEE Std 1278.1, with the field name italicized and followed by its definition. Record formats are presented in a table showing the component fields, field sizes, and data types.

Add a Jammer Architecture Field

The Jammer Architecture field is used to provide a higher fidelity representation of the jamming beam signal as compared to the radar reflection from the target, aka the skin return. It’s a surrogate for the fidelity of the jamming beam signal to indicate all the different aspects of an electromagnetic transmission that are mimicking the skin return, but without the extraordinary amount of data required to completely define the jamming waveform. Jammer architecture information provides added granularity necessary to discriminate between older and modern jammer systems and allow the radar model to produce models at a higher level of detail to support complex electronic warfare interactive simulations. Details regarding specific applications are beyond the scope of this paper.

Jammer Architecture. This field shall specify the jammer architecture. It shall be represented by a 16-bit enumeration that provides an indication of the signal fidelity of the jammer waveform. The Jammer Architecture values are enumerated as follows:

- None (0): This value is used when the beam is not a jammer beam.
- Other (1): The jammer architecture is not specified; a higher fidelity representation of the jamming beam signal is not being used.

- Transponder (10): Transponders generate non-coherent signals that emulate the temporal characteristics of the actual radar return.
- Analog Repeater (20): Analog Repeaters generate coherent returns that attempt to emulate the amplitude, frequency, and temporal characteristics of the actual radar return. Repeaters usually require some form of memory for microwave signals to allow anticipatory returns to be generated; this is usually accomplished by using a microwave acoustic memory.
- Digital Radio Frequency Memory (DRFM) (30): A repeater with digital radio frequency memory. In a DRFM system, the stored signals can be manipulated in amplitude, frequency, and phase to generate a wide range of jamming signals.
- Direct Digital Synthesis (DDS) (40): In a DDS system, all the parameters of the waveform: frequency, phase, and amplitude, are defined by digital words. The advantages of direct digital synthesizers are the following: a wide range of synthesized frequencies, an ultralow frequency spectrum pitch, an extremely fast frequency tuning rate, phase continuity during frequency tuning, the low level of phase noises, a simple algorithm of complex signals forming, the possibility of independent control of the amplitude, phase and frequency of a synthesized signal, good repetition of parameters during replication, and the stability of parameters under the influence of destabilizing climatic and mechanic factors.

If a higher fidelity representation of a jamming beam signal is desired, the Jammer Architecture field is set to the enumeration that corresponds to the jammer architecture transmitting the jamming beam. Otherwise the Jammer Architecture field is set to Other (1).

Add a Jamming Attributes Field

Jamming attribute data is a valuable resource for high fidelity susceptibility decisions made within the receiving radar model. The jamming attributes define characteristics unique to a jamming beam signal that extend on the available meta-information provided by the jammer architecture and the jamming technique(s).

Jamming Attributes. This field shall specify the jamming attributes. It shall be represented by a 16-bit set of flags that are independent from the jamming techniques and provide the following additional information about the jamming beam signal. The bit fields are defined below.

- Persistent (Bit 0): 0 means not persistent and 1 means the jamming technique(s) are persistent over time. For example, when a jammer is generating multiple false targets, this flag would indicate whether the targets are random (not persistent), or if they are persistent with corresponding location and velocity behavior over time.
- Constant Gain or Constant Power (Bit 1): 0 means the jamming technique(s) are transmitted with constant power over time and 1 means the jamming technique(s) are transmitted with constant gain over time.
- Coordinated (Bit 2): 0 means not coordinated and 1 means multiple jamming techniques are coordinated in their electromagnetic characteristics. For example, when a jammer is employing both velocity gate pull-off and range gate pull-off techniques and they are coordinated, then the velocity gate pull-off Doppler shift correlates to the range gate pull-off change in range over time. If this bit is set, there must be at least two jamming techniques in the jammer beam signal.
- Cooperative (Bit 3): 0 means not cooperative and 1 means the jamming technique(s) are being deployed cooperatively with another jamming system. For example, consider a scenario where there are two jammers on separate platforms cooperatively using blinked noise against a victim radar. Each jammer will set the Cooperative bit to 1. The receiving radar receives jammer beams from the cooperating jamming platforms with the following characteristics:
 - Cooperative bit is set to 1 in both (or multiple) jamming beams
 - Same frequency (or very close)
 - Same jamming technique(s)
 - Both (or multiple) jamming beams include the victim radar and beam in their track/jam list data (Entity ID, Emitter Number, Beam Number)
- Coherent (Bit 4): 0 means not coherent and 1 means coherent, where a jammer is maintaining consistent spatial and temporal phase relationships between the victim radar signal received by the jammer and the resulting jamming waveform.

- Bounce (Bit 5): 0 means no intentional bounce and 1 means the jamming waveform is being intentionally bounced (i.e., reflected) off the terrain surface. Bounce jamming indicates to the receiving victim radar simulation that the beam is intended to reflect off the terrain surface and should not be processed from the aspect angle of the jammer.
- Downlink (Bit 6): 0 means no downlink and 1 means downlink, where the jamming waveform is intended for the downlink receiver of a radar and not the aircraft target tracking radar beam.

For a non-jammer beam this field shall be set to zero.

The format of the Jamming Attributes record is shown below in Table 2.

Table 2 – Jamming Attributes

Field Name	Bit	Data type
Persistent	0	1-bit enumeration
Constant Gain or Constant Power	1	1-bit enumeration
Coordinated	2	1-bit enumeration
Cooperative	3	1-bit enumeration
Coherent	4	1-bit enumeration
Bounce	5	1-bit enumeration
Downlink	6	1-bit enumeration
Padding	7-15	9 bits unused
Total Jamming Attributes record size = 16 bits		

Add Support for Multiple Jamming Techniques

The final proposed change for the IEEE Std 1278.1 Electromagnetic Emission PDU is to add support for multiple jamming techniques. Multiple jamming techniques used simultaneously in a jamming beam signal are specified by including the enumerations of multiple individual jamming techniques within the Array of Jamming Techniques and specifying the corresponding number in the Number of Jamming Techniques field. These protocol data items are depicted in Figure 3 as previously discussed.

Number of Jamming Techniques. This field shall specify the number of jamming techniques simultaneously used in this beam. Multiple jamming technique entries shall represent a combination of jamming techniques transmitted in the beam. It shall be represented by a 16-bit unsigned integer.

Array of Jamming Techniques. The collection of simultaneous jamming techniques used to conduct electronic warfare shall be specified by an array of Jamming Technique records. The Jamming Technique record shall contain the following five fields, where each field is an 8-bit enumeration:

1. *Type.* This field shall indicate the type of jamming, which is the broadest category of jamming.
2. *Intent.* This field shall specify the intent of the jamming.
3. *Waveform.* This field shall specify the type of radio frequency waveform.
4. *Modulation* This field shall specify the type of modulation of the jamming signal.
5. *Specific.* This field shall provide a means to uniquely specify jamming techniques.

The enumeration values for the five Jamming Technique components are defined earlier in this paper, in Figure 1.

If the beam is not a jamming beam, the Number of Jamming Techniques field is set to zero, and there are no jamming techniques represented in the beam data.

To transmit a jamming beam with a single jamming technique, such as Spot Noise, the Number of Jamming Techniques field is set to 1, and the Array of Jamming Techniques is a one-entry array with the enumeration that represents Spot Noise.

If there are multiple simultaneous jamming techniques being represented, for example Range Gate Pull-Off and Velocity Gate Pull-Off, the Number of Jamming Techniques field is set to the appropriate value; in this case the field would be set to 2. The Array of Jamming Techniques is then a two-entry array with the enumeration that represents Range Gate Pull-Off as one entry, and the enumeration that represents Velocity Gate Pull-Off as the other entry. This represents both jamming techniques as simultaneous characteristics of the associated jamming beam.

CONCLUSION

Results

The authors identified a much-needed improvement for electronic warfare distributed interactive simulation: to provide authoritative definitions of the jamming techniques listed in SISO-REF-010. During the effort to achieve this goal, it became obvious that the jamming technique hierarchy needed to be redesigned as well. And in addition, several changes were needed in the IEEE Std 1278.1 Electromagnetic Emission PDU.

The results of this effort, as presented in this paper, are detailed and significant proposed changes for both the SISO-REF-010 enumerations and the IEEE Std 1278.1 protocol. These proposals include the jamming technique definitions for the new hierarchy, and much more.

Collectively, the proposed changes provide a common understanding of simulated radar jamming techniques, correct problems with the current simulation jamming technique hierarchy, and provide an enhancement in the fidelity of simulated jamming interactions. The proposals also support a smooth transition from the old paradigm to the new paradigm, and the new paradigm provides support for interoperability between systems that operate at different levels of electronic warfare fidelity.

Status and Future Expectations

The change proposals discussed throughout this paper are in development and are being coordinated with the respective SISO working groups. The plan is to complete the change proposal products and then engage with the international simulation community in a collaborative environment to ensure they meet broad user needs and undergo critical peer review and any necessary improvements can be identified and incorporated. Fortunately, the timing worked out perfectly for these significant changes to merge with the much larger on-going effort to create the next version of IEEE Std 1278.1: Version 8, along with associated changes and updates for SISO-REF-010.

While the proposed changes offer a significant improvement in the support of higher fidelity electronic warfare simulation, even more is possible. If the simulation community wants to go further, for example, if there is a requirement to represent rates, excursions, and profiles data for specific jamming techniques, additional Electromagnetic Emission PDU expansion records may be developed to accomplish additional levels of fidelity. In fact, there are three examples in the current IEEE Std 1278.1 that could be used as a reference for consideration: see the Electromagnetic Emission attribute records for Blanking Sector, Angle Deception, and False Targets. While the proposed changes from this effort are general in nature, these examples, combined with the new extensibility being integrated into the architecture of IEEE Std 1278.1, provide an opportunity and ideas for how specific jamming techniques could be greatly enhanced with higher fidelity representation and data.

REFERENCES

- Avionics Department, (2013). *Electronic Warfare and Radar Systems Engineering Handbook, Fourth Edition*, Naval Air Warfare Center Weapons Division.
- Barton, David K., (2005), *Radar System Analysis and Modeling*, Boston, MA: Artech House.
- Barton, David K., (2013), *Radar Equations for Modern Radar*, Boston, MA: Artech House.
- Brooks, Charles, & Haber, David, & Merlet, Patrick, (2018), *Jamming Techniques and their Usage in Distributed Electronic Warfare Simulation*, Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2018, Paper No. 18252.
- Curry, G. Richard, (2005), *Radar System Performance Modeling*, Boston, MA: Artech House.
- Chen, Hung-Ruei, (2013) FMCW radar jamming techniques and analysis, Naval Postgraduate School.
- Chrzanowski, Edward J., (1990) *Active Radar Electronic Countermeasures*, Boston, MA: Artech House.
- Denk, Aytug, (2006) DETECTION AND JAMMING LOW PROBABILITY OF INTERCEPT (LPI) RADARS, NAVAL POSTGRADUATE SCHOOL.
- Falk, Lars, (2007) Cross-Eye Jamming of Monopulse Radar, FOI, Swedish Defence Research Agency, *IEEE Waveform Diversity & Design*.
- Graham, Adrian, (2011). *Communications, Radar and Electronic Warfare*, West Sussex, UK: John Wiley & Sons Ltd.
- Hill, Peter C.J., & Truffert, Vincent, (1992), Statistical Processing Techniques for Detecting DRFM Repeat-Jam Radar Signals, *IEE Colloquium on Signal Processing Techniques for Electronic Warfare*, London UK, pp-1/1-1/6.
- Hingwala, Chirag, (2011), Investigation of a Novel Software Based Laboratory Jammer Architecture, Ottawa-Carleton Institute for Electrical and Computer Engineering, Carleton University, Ottawa, Ontario, pp-24-25.
- IEEE, (2012), *IEEE Standard for Distributed Interactive Simulation—Application Protocols*, IEEE Std 1278.1-2012.
- Kemkemian, S., & Nouvel-Fiani, M., & Chamouard, E., (2011), Radar and Electronic Warfare Cooperation: How to Improve the System Efficiency, *IEEE A&E Systems Magazine*.
- Lothes, Robert N., (1990), *Radar Vulnerability to Jamming*, Boston, MA: Artech House.
- Nathanson, Fred E., (1999), *Radar Design Principles Signal Processing and the Environment, Second Edition*, Mendham, NJ: SciTech Publishing Inc.
- I. V. Ryabov, I. V. Strelnikov, S. V. Tolmachev and E. S. Kljuzhev (2019). Direct Digital Synthesizers of Complex Broadband Signals, *2019 Systems of Signals Generating and Processing in the Field of on Board Communications*, pp. 1-4.
- SISO, (2019), *Reference for Enumerations for Simulation Interoperability*, SISO-REF-010-2019.
- Schleher, D. Curtis, (1999), *Electronic Warfare in the Information Age*, Norwood, MA: Artech House.
- Singh, Mohinder, (1988), *Electronic Warfare*, New Delhi: Defence Scientific Information & Documentation Centre.
- Skolnik, Merrill I., (2008), *Radar Handbook Third Edition*, New York NY, McGraw Hill.
- Skolnik, Merrill I., (1980), *Introduction to Radar Systems*, New York NY, McGraw Hill.
- Stephens, James P., (1996), Advances in Signal Processing Technology for Electronic Warfare, *IEEE Aerospace and Electronic Systems Magazine*, vol. 11, no. 11, pp. 31-38

Technical Staff, Intel Corporation, (1991) Introduction to Direct Digital Synthesis, *Application Note 101*

Thayaparan, T., & Abrol, S., & Riseborough, E., (2004), *Micro-Doppler Radar Signatures for Intelligent Target Recognition*, Defence Research and Development Canada, DRDC Ottawa.

Tolk, Andreas, (2012), *Engineering Principles of Combat Modeling and Distributed Simulation*, Hoboken, NJ: John Wiley & Sons.

Vakin, Sergie A., (2001), *Fundamentals of Electronic Warfare*, Boston, MA: Artech House.

Van Brunt, L., (1985). *Applied ECM Volume 1 (5th Printing)*, Dunn Loring, VA: EW Engineering Inc.

Van Brunt, L., (1985). *Applied ECM Volume 2 (2nd Printing)*, Dunn Loring, VA: EW Engineering Inc.

Van Brunt, L., (1995). *Applied ECM Volume 3 (1st Printing)*, Dunn Loring, VA: EW Engineering Inc.