CASE 86

Robust Testing of Electronic Warfare Systems

Abstract: The process of development testing for electronic warfare (EW) systems can be both expensive and time consuming, since the number of individual radar emitter types and modes is large. Robust engineering methods have been applied to development testing of EW systems whereby the confirmed test cycle time has been decreased significantly, by a factor of 4 to 1, while providing equivalent diagnostics of system performance. An L_{18} array has effectively demonstrated the ability to test more system functionality in significantly less time than do conventional methods.

1. Introduction

The development of EW systems includes testing and evaluation of new systems against a wide and varied range of radar emitter types, taking a significant amount of time and effort. To minimize development time while improving product quality and performance, robust engineering methods were implemented. The objective was to reduce EW system test time for a large quantity of emitters by defining a reduced set of orthogonal emitter types.

2. Experimental Approach

Most quality engineering methods employ control factors to determine the sensitivity of system performance to various design parameters. In this situation the approach was used to evaluate a system's performance against a wide variety of simulated field conditions (noise factors), in a time-efficient manner. A secondary goal is to determine system deficiencies in order to develop a more robust system design. A third result of the task was to yield a single measure of system performance (mean signal-to-noise ratio) to track hardware and software improvements. Since the objective of this task was to permit detection, noise factors were selected in lieu of control factors to define the orthogonal array selected.

The purpose of an EW system is to search for various radar systems (emitters) in its operational environment, determine their location, and classify function by measuring various radiated parameters and received characteristics. If a radar site is considered hostile, effective measures are taken by the EW system to mitigate emitter function. This is illustrated in Figure 1. As an example, airport radar systems may be searching for aircraft, whereas a hostile emitter site may be seeking to launch and control armaments. The determination of radar type (airport, hostile, etc.) and radar mode (search, acquisition, track) is therefore a very critical function. The scope of this project was limited to assessing EW system performance to identify a radar system and its mode correctly.

The electronic warfare system makes these critical determinations by measuring various characteristics of a radar's transmitted signal. Measuring the signal amplitude from two or more EW system receiving antennas permits the determination of radar position by determining the angle of arrival (AOA). Measuring parameters transmitted from the radar, such as the frequency, pulse, scan type, and amplitude, help determine the type and mode of the radar system. These parameters become noise factors for an orthogonal array.

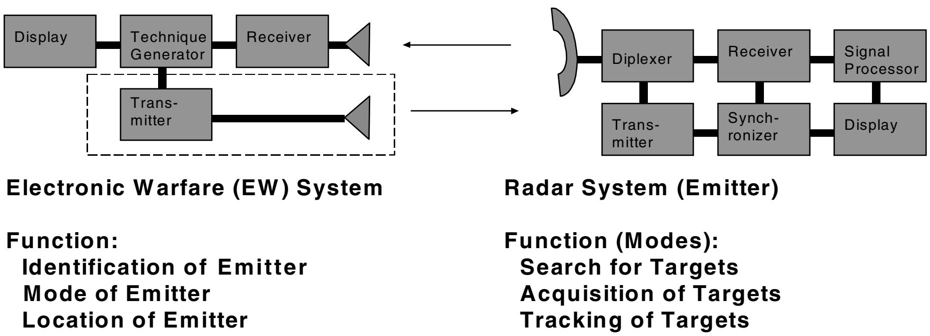

Figure 1
Electronic warfare scenario

The challenge for this project was to select a signal (limited group of emitters) that represents the functional variation of the entire ensemble of radar types. The transfer function is to identify each emitter in the signal set without error. The Taguchi problem type was selected to be "maximum the best," given that correct identification of the emitter is considered to be a correct signal, and any error in the system output is considered noise. In this case the system must detect all signals without radar type or mode identification error.

It is recognized that the EW system will need to be tested against the entire group of radar systems. However, since software upgrades are made on a nearly weekly basis, the 16 hours required to evaluate the entire ensemble of emitter types becomes expensive and time consuming. The goal of this project was therefore to cut the weekly 16 hours of test time by at least one-half while maintaining test integrity.

3. P-Diagram

Figure 2 illustrates the P-diagram for this project. The input signal is the domain of emitters as described by the L_{18} array. The output signal is correct identification of each radar emitter and mode to which the EW system is subjected. The control factors consist of the EW system hardware and software configuration that is tested in a particular system configuration. The system configuration is variable depending on project phase due to improvements in hardware and software.

Noise factors are those that define the variable domain of conditions to which the EW system is subjected. This includes the variation in emitter characteristics over the domain of all emitter types; the variation in emitter position, including angle of arrival and signal amplitude; the variation in emitter mode; and the background noise.

4. Selection of Orthogonal Array

Selection of array size was based on the determination of one two-level factor and five three-level factors. (Table 1).

The L_{18} array was selected because it has more than 14 degrees of freedom and will accommodate one two-level factor and up to seven three-level factors. Selection of an L_{18} array will also yield growth for two three-level factors, as noted in Table 1. The next issue in developing this project was selection of 18 emitters from a group on the order of 100 in size.

5. Selection of Robust Emitter

Selection of emitters started with the characterization of each radar system in the total domain in terms of the noise factors and parameters selected. The orthogonal array is based on the noise factors shown in Table 1. Hence, each of the 18 experiments defined by the array would consist of a different set of emitter characteristics. Table 2 illus-

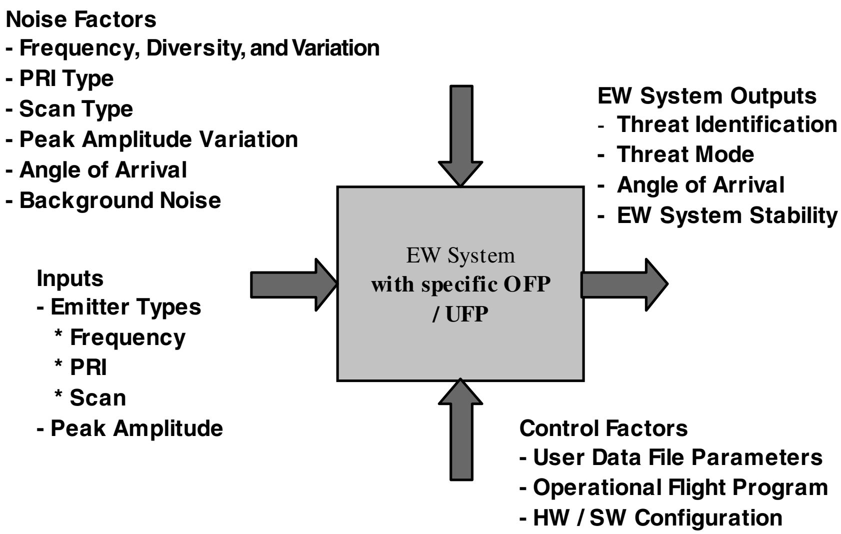

Figure 2
P-diagram

Table 1
Selection of array

Factor	Level 1	Level 2	Level 3	d.f.
Overall mean	—	—	—	1
Frequency diversity	Single	Multiple	—	1
Frequency	Low	Mid	High	2
PRI type	CW	Stable	Agile	2
Scan type	Steady	Circular	Raster	2
Peak power	Nominal	Medium	Low	2
AOA[a]	Boresite	Offset 1	Offset 2	2
Illumination	Short	Medium	100 %	2
Background[a]	None	Low density	High density	2
			Total	16

[a] Growth factor.

Table 2
Selection of 18 robust emitters

Experiment	Item	Mean Distance	RF Diversity	RF	PRI Type	Scan Type	Peak Power	Illumination
2	76	1	Single	High	Stable	Circular		Medium
			Single	High	Stable	Circular		Short
	Item	**Item Distance**	**RF Diversity**	**RF**	**PRI Type**	**Scan Type**	**Peak Power**	**Illumination**
	66	4	0	1	1	1		1
	70	2	0	0	1	0		1
	74	2	0	1	0	0		1
	76	1	0	0	0	0		1
	80	3	0	0	1	1		1
	82	3	0	1	1	1		0
	83	2	0	0	0	1		1
	84	2	0	0	0	1		1
	88	4	1	1	1	0		1
	90	3	0	0	1	1		1

trates the selection process for experiment 2. The principal characteristics were single RF frequency, high RF frequency, stable PRI, circular scan, and short illumination time. The difficulty in choosing emitters from the ensemble available was that only a few provided a perfect match to the Taguchi-defined set. This problem was handled by calculating the shortest distance for each emitter in the ensemble against the 18 experiments defined.

Table 2 shows that for experiment 2, the shortest distance exists for item 76, with the only incorrect parameter being short illumination time, hence a distance of 1. Item 76 was therefore selected for experiment 2. Peak power was adjusted for each experiment and therefore was not considered in the selection process. Note that "0" indicates an exact correlation to the desired parameter, and "1" indicates no match. All experiments were selected in the same manner.

Table 3 presents the entire set of 18 test emitters. Several experiments match the orthogonal requirement exactly with an item distance of zero. Several emitters, such as item 76 used in experiment 2, are not quite orthogonal. That is, the distance is other than zero, either 1 or 2. The correct or desired parameter is located in the center of each parameter box, while the parameter exhibited by the emitter is located underneath. The count of valid parameter matches and incorrect matches are summed at the bottom of each factor column. The important point to be made here is that an orthogonal array selected for the purpose of cause detection need not be exactly orthogonal to be effective.

6. Signal-to-Noise Ratio

The ideal transfer function for this problem is to identify each emitter and its mode without error over the domain of emitter types. Each emitter was tested and evaluated to determine whether its radar type, radar mode, and angle of arrival were correct. Any incorrect output was assigned a count of 1 per incorrect output. Since there may be subjective considerations during this evaluation, the operator also

Table 3
L_{18} array for robust testing of EW systems

Experiment	Item	Distance Item (Mean)	Expert Array Laboratory Performance: Column Factor and Parameter Assigned								Observation
			A RF Diversity	*B* RF	*C* PRI Type	*D* Scan Type	*E* Peak Power	*F*	*G* Illumination	*H*	m_1 (Defects)
1	10	0	Single	High	CW	Steady	Nominal	F_1	100%	H_1	1.000
2	76	1	Single	High	Stable	Circular	Medium	F_2	1 Medium Short	H_2	0.000
3	80	0	Single	High	Agile	Raster	Low	F_3	Short	H_3	6.000
4	61	1	Single	Mid	CW	Steady	Medium	F_2	1 Short 100%	H_3	0.000
5	12	1	Single	Mid	Stable	1 Circular Steady	Low	F_3	100%	H_1	4.000
6	70	2	Single	1 Mid High	Agile	Raster	Nominal	F_1	1 Medium Short	H_2	0.000
7	33	0	Single	Low	CW	Circular	Nominal	F_3	Medium	H_3	2.000
8	147	0	Single	Low	Stable	Raster	Medium	F_1	Short	H_1	0.000
9	141	1	Single	1 Low Mid	Agile	Steady	Low	F_2	100%	H_2	2.000
10	82	2	1 Multiple Single	1 High Mid	CW	Raster	Low	F_2	Medium	H_1	3.000
11	5	2	Multiple	1 High Low	Stable	1 Steady Circular	Nominal	F_3	Short	H_2	2.000
12	89	2	Multiple	1 High Mid	Agile	Circular	Medium	F_1	1 100% Short	H_3	4.000

Table 3
(Continued)

Experiment	Item	Distance Item (Mean)	Expert Array Laboratory Performance: Column Factor and Parameter Assigned								Observation m_1 (Defects)
			A RF Diversity	*B* RF	*C* PRI Type	*D* Scan Type	*E* Peak Power	*F*	*G* Illumination	*H*	
13	65	0	Multiple	Mid	CW	Circular	Low	F_1	Short	H_2	2.000
14	69	1	1 Multiple Single	Mild	Stable	Raster Conical	Nominal	F_2	100%	H_3	0.000
15	149	2	Multiple	Mild	Agile	1 Steady Raster	Medium	F_3	1 Medium Short	H_1	4.000
16	32	1	1 Multiple Single	Low	CW	Raster Conical	Medium	F_3	100%	H_2	1.000
17	134	1	Multiple	Low	Stable	Steady	Low	F_1	1 Medium 100%	H_3	0.000
18	155	1	1 Multiple Single	Low	Agile	Circular	Nominal	F_2	Short	H_1	0.000
Iteam mean		1.00									
Total fault analysis											
Valid (mean)		15.75	14	13	18	15	18	18	12	18	
Incorrect (mean)		2.26	4	5	0	3	0	0	6	0	

places a “color” valuation on the experiment in the form of green, yellow, or red (a defect count of 0, 1, or 2, respectively). Green is a stable signal with no variations or anomaly, yellow may indicate some concern regarding timeliness or stability of the identification, and red indicates a more serious malfunction, such as multiple emitter types identified for the one emitter tested. Typical emitter performance evaluation was graded as shown in Table 4.

The signal-to-noise (SN) ratio for this experiment was calculated using the relationship

$$\text{SN} = -20 \log\left(\frac{\text{total defects}}{n + 1}\right)$$

Since the problem type is “maximum-the-best”, the SN ratio for a perfect system is 0 dB. Any error in performance yields a negative SN ratio. The relationship including “defects plus one” was used since the log (0) was undefined and log (1) was zero. The value for n is 18 to compute the entire array SN ratio, while n may vary from mean parameter count (6 or 9) because certain emitters were not perfect orthogonal fits. As an example, the RF diversity factor is segmented with $n = 5$ for the parameter “multiple” and $n = 13$ for the parameter “single.”

A sample calculation is shown here for computing the SN ratio for “RF diversity.” Since this is a two-level factor, an orthogonal array would contain nine entries for the parameter “single” and nine entries for the parameter “multiple.” Since only five of the experiments contain the parameter “multiple,” only those parameters are used for the calculation. These include experiments 11, 12, 13, 15, and 17. Hence,

Table 4
Calculation of emitter performance

Experiment (Emitter)	Defects				
	Type	Mode	AOA	Color	Total
1	0	0	1	0	1
2	0	0	0	0	0
3	2	2	0	2	6

$$\text{SN} = 20 \log\left(\frac{M_{11} + M_{12} + M_{13} + M_{15} + M_{17}}{5 + 1}\right)$$

$$\text{SN} = 20 \log\left(\frac{2 + 4 + 2 + 4 + 0}{5 + 1}\right)$$

$$= -\ 10.6 \text{ dB}$$

For the parameter “single,”

$$\text{SN} = 20 \log \left(\frac{\begin{array}{l} M_1 + M_2 + M_3 + M_4 \\ + M_5 + M_6 + M_7 + M_8 + M_9 \\ \quad + M_{10} + M_{14} + M_{16} + M_{18} \end{array}}{13} + 1\right)$$

$$\text{SN} = 20 \log \left(\frac{\begin{array}{l} 1 + 0 + 6 + 0 + 4 + 0 + 2 \\ \quad + 0 + 2 + 3 + 0 + 1 + 0 \end{array}}{13} + 1\right)$$

$$= -7.8 \text{ dB}$$

7. Confirmation

The reduction in test time surpassed the goal of a 50% decrease in weekly test time. The 18 emitters can be tested in only four hours, a reduction of 4:1 in effort. This is quite significant given that the sensitivity to test results did not yield any additional system weakness when the monthly test sequence was conducted. The monthly test sequence extended over a 16-hour period, with a number of emitters remaining to be evaluated.

Table 5 shows test results during several weeks of development but does not represent the final system configuration. Several important results can be observed from this table:

1. The overall SN ratio increased from −9.4 dB to −5.0 dB. This yields a steady improvement for each system upgrade, which can be used to track system performance.
2. From the first test conducted, the system demonstrated a sensitivity to input signal peak power. This was significant because peak power is one parameter that is not normally evaluated in the conventional sequence, due

Table 5
System performance summary

Factor/ Parameter	Test					
	1	2	3	4	5	6
Mean SN ratio (dB)	−9.4	−8.2	−8.7	−6.9	−5.8	−5.0
RF diversity						
Single	−8.9	−5.0	−7.8	−5.0	−5.3	−3.3
Multiple	−10.6	−13.3	−10.6	−10.6	−6.9	−8.3
RF frequency						
Low	−8.8	−2.0	−8.8	−4.9	−3.5	0.0
Mid	−10.9	−9.5	−10.6	−8.8	−7.5	−8.8
High	−7.4	−9.1	−5.3	−5.3	−4.4	−0.0
PRI type						
CW	−9.5	−2.5	−8.0	−4.4	−1.3	−6.0
Stable	−8.2	−9.5	−6.0	−8.0	−8.0	−2.5
Agile	−10.0	−10.5	−11.3	−8.0	−6.7	−6.0
Scan type						
Steady	−13.3	−5.1	−7.6	−6.0	−6.8	−5.1
Circular	−7.6	−11.6	−8.3	−9.5	−7.6	−6.8
Raster	−7.0	−7.0	−9.6	−5.5	−3.5	−3.5
Peak power						
Nominal	−4.4	−6.7	−5.3	−5.3	−1.3	0.0
Medium	−8.5	−10.9	−8.0	−6.7	−7.4	−4.4
Low	−13.0	−6.0	−11.7	−8.5	−7.4	−8.5

to the large quantity of emitters tested. Test 2 shows an improvement in the mean SN ratio not consistent in sequence with the remainder of the group. Upon investigation it was determined that correct peak power levels were not maintained for that group. It was therefore concluded that the Taguchi method identified, early in the development process, a system-sensitive parameter that would not normally have been recognized.

3. The Taguchi method provides a perspective of system performance perhaps not readily evident when testing a group of independent emitter types. That is the correlation of EW system sensitivity to the specific noise factors selected.
4. Additional tests may be added to the L_{18} array to provide an added level of robustness to the project. As noted in Table 1, the emitter angle of arrival and background noise have been noted as noise factors but not yet implemented. Angle of arrival testing will consist of placing the emitter at three different angular positions from the EW system. Background noise has been defined to simulate unknown emitter types.

8. Conclusions

An L_{18} orthogonal array was employed successfully to yield a robust test methodology for EW systems. The robust group of 18 emitter types, coupled with operationally based noise factors, has surpassed the capability established by testing each radar type individually. Analysis of the L_{18} test results compared with test results from the entire domain of emitters demonstrates that the L_{18} can find more system sensitivities than testing the entire ensemble of emitters in a conventional manner.

What is more, the L_{18} array used contained experiments (emitters) that were not quite orthogonal, thereby permitting a selection of emitters from a standard group. This eliminated the time and effort necessary to generate simulations for a new, albeit not real emitter set. The L_{18} orthogonal array has effectively demonstrated the capability to test more system functionality in significantly less time than is possible using conventional methods.

This case study is contributed by Stan Goldstein and Tom Ulrich.