Proceedings of the 1985 Winter Simulation Conference
D. Gantz, G. Blais, S. Solomon (eds.)

SIMULATOR BASED PROGRAMMABLE SIGNAL GENERATOR FOR EW SYSTEM EVALUATION

Saul Fast
McDonnell Douglas Corp., St. Louis, Mo

A test range that generates signals at RF capable of evaluating EW systems capability for operation in a dense signal environment is excessively costly in terms of equipment and range maintenance personnel. The required test equipment complement is reduced by two orders of magnitude through use of a programmable signal source operating at IF. Design methodology/technology for a generic programmable signal source is discussed. Detailed modeling of antenna/receiver front end components of each candidate EW system is required to generate a simulation of the worst case frequency step that yields data for programming the signal source control sequence.

AIRBORNE EW SYSTEMS EVALUATION

An airborne EW system (Figure 1) consists of: (a) antenna arrays that accept signals over an extended field of view within an extended frequency band and generate phase and/or amplitude differences for each signal to permit determination of direction of arrival, (b) receiver front ends that provide filtering to limit spurious responses generated in the mixer and control system noise figure to limit random parameter measurement errors, (c) the IF section that determines the system frequency acceptance bandwidth and, hence, pulse and CW signal density, (d) the detector set that measures signal parameters within specified ranges with specified accuracies and (e) hardware and/or software signal processors that extract information from the signal measurements.

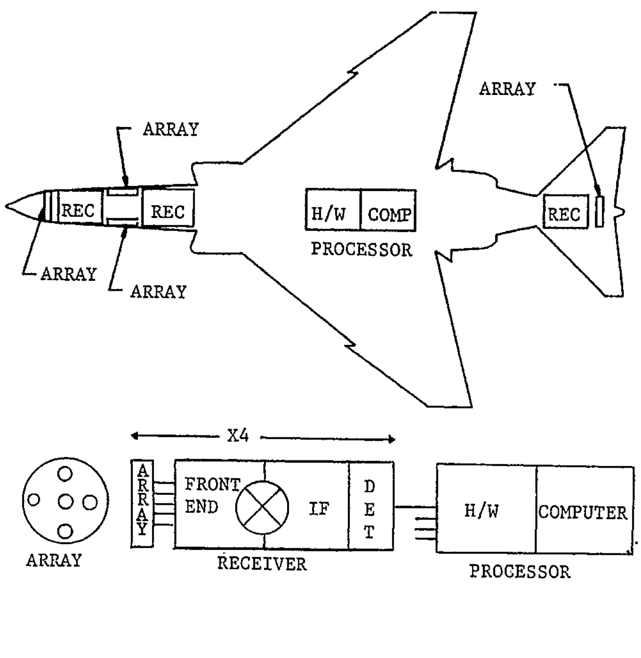

Figure 1: Airborne EW System

The processors sort signals by emitter, resolve interferometer ambiguities estimate emitter parameters, and prioritize system responses. Each of these processes are degraded when the signal density is increased since the occurrence of pulse overlaps increases with pulse arrival rate (and population mean pulse width) and overlapped pulses result in corrupted parameter measurements.

Typically systems evaluation has been concerned with determination of system sensitivity, parameter measurement accuracy and ability to operate over the specified field of view/frequency band. A test and evaluation range generates a limiting set of emitter signals to exercise the airborne system and a comparison is made of system output vs range emitter parameters. Auxiliary range and aircraft instrumentation assist in pinpointing error sources.

The extreme density of the emitter environment greatly compounds the requirements for a test range capable of exercising the system signal processors. A brute force approach for test range implementation that approximates the worst case emitter density is simply too costly in terms of equipment amd range maintenance personnel to be feasible.

This paper discusses practical methodology/technology that can provide, at low cost, the necessary signals to exercise the signal processors. Reduction of the required range source complement is based on the principal that demonstration of the ability of the system signal processors to cope with the dense environment does not require transmission of all emitted signals, only those collected during the worst case frequency step.

These signals include the valid signal population in the acceptance band of the worst case step and the population of spurious responses generated for all spur product types generated in the mixer.

Consider a test range that generates at RF the valid and spur populations for the worst case dwell for various customer EW systems. The spur response emitter complement for each system would be different since it is specific design dependent. A generic range equipment complement would require the envelope of the equipment complements for each possible specific EW system and would approximate in cost and complexity the range not limited to the worst case dwell.

Before proceeding to definition of a greatly simplified range methodology, an additional complication is noted for ranges that generate the required signals at RF, whether limited to the worst case dwell or not. Each RF signal source must be modeled for amplitude and frequency and, in addition, must be specifically located.

IF SIGNAL SOURCES

The required reduction in cost and complexity is based on generation of the signals present in each receiver IF during the worst case dwell through use of a relatively small number of rapidly programmable pulse signal generators. For each pulse the signal amplitude, pulse shape and frequency is programmed. Controlled phase differences between IF pulse signals are programmed in accordance with the emitter's direction of arrival.

Definition of the programmable IF signal generator entails the following sequence:

(1) Determination of the worst case frequency step using a model of the emitter environment.

(2) Simulation of the IF signal for the worst case frequency step.

(3) Determination of the required number of programmable pulse signal generators.

DETERMINATION OF THE WORST CASE FREQUENCY STEP

The worst case frequency step is determined by computation of the fraction of the valid signals in each frequency step that are corrupted by (a) mutual self overlap and (b) overlap with spurious responses. The frequency step with greatest combined fraction of overlapped pulses is chosen for simulation.

The required computations are based on analysis derived from Poisson statistics. Consider any dwell wherein pulses are collected from V valid emitters. If r_i and y_i are the arrival rate and p ulse width for pulses collected from emitter i (i = 1, 2...V), the combined arrival rate, r_v, and mean pulse width y_v for the valid pulse population are given by:

$$r_v = \sum_{i=1}^{V} r_i; \quad y_v = (\sum_{i=1}^{V} r_i y_i)/r_v \tag{1}$$

Consider the population formed from the pulses derived from all valid signal emitters except emitter i. The arrival rate, r_o, and mean pulse width, y_o, of this population is given by

$$r_o = r_v - r_i; \quad y_o = (r_v y_v - r_i y_i)/r_o \tag{2}$$

If spurious response pulses are collected during the dwell from S emitters, with r_j and y_j the arrival rate and pulse width of pulses collected from emitter j (j=1, 2...S), the combined arrival rate, r_s, and mean pulse width, y_s, for the spurious response pulse population are given by:

$$r_s = \sum_{j=1}^{S} r_j; \quad y_s = (\sum_{j=1}^{S} r_j y_j)/r_s \tag{3}$$

Given a pulse arrival rate, r, the probability that K pulses are collected during a dwell interval X is given by the Poissan distribution:

$$p(K) = \exp(-rx) \cdot (rx)^K/K! \tag{4}$$

Given pulses collected from valid emitter i (arrival rate r_i, pulse width y_i) and a population of other pulses (arrival rate r_o; mean pulse width y_o), a given pulse from emitter i is overlapped of one or more of the pulses from the other population occurs during an interval of length $y_o + y_i$. From (4) the probability that an emitter i pulse is overlapped.

$$P_i = \sum_{K=1} \exp[-r_o(y_o + y_i)] \cdot [r_o(y_o+y_i)]^K/K! \tag{5}$$

$$= 1 - \exp[-r_o(y_o+y_i)]$$

For the valid signal population (arrival rate r_v; mean pulse width y_v), r_o and y_o for emitter i is determined from (2). Hence the fractional loss of valid signals in the dwell due to self overlap is:

$$P_v = (\sum_{i=1}^{V} r P_i)/(\sum_{i=1}^{V} r_i) = (\sum_{i=1}^{V} r_i P_i)/r_v \tag{6}$$

Similarly the probability that a valid signal pulse from emitter i is overlapped by a pulse from the spurious emitter population (arrival rate r_s, mean pulse width y_s is derived from (5):

$$P_{is} = 1 - \exp[-r_s(y+y_i)] \tag{7}$$

The fractional loss of valid signals due to overlap with spur pulses:

$$P_s = (\sum_{i=1}^{V} r_i P_{is})/r_v \tag{8}$$

The required population parameters r_i, y_i for each valid signal and r_j, y_j for each spur signal are determined for each frequency step from an emitter model.

THE EMITTER MODEL

A generic emitter model derives from a geographic map of threat and friendly emitters. Data definition for each emitter consists of its location, transmission/radiation parameters (radiated power, pattern shape, search sector/period) and modulation signature parameters (radiated frequency, signal waveform).

The emitter model is simplified considerably through use of statistical parameter definition. For example, the emitter radiation parameters may be defined by probabilities that the emitter is within the emitter pattern half-power points, between the half-power points and the first nulls, and in the sidelobe/backlobe region from first null to first null and the conditional probability distribution for antenna gains given that the received signals derive from each of the three regions. For another example the signal waveforms parameters are defined by the pulse repetition rate and pulse width which are the parameters required to compute pulse overlap based on Poisson statistics.

For each frequency step, defined by a local oscillator setting and the IF band, valid signals derive from specific frequencies in a band equal in width to the IF. The spurious response population derives from a pair of bands for each j-k spur product type (where j=1,2,3,4 and k=1,2,3,4). The 1-1 spur frequency is the image. The bandwidth of each band for a j-k spur is equal to the IF band divided by j. The center frequencies for the two j-k spur bands are located at $|kf_L \pm f_i|/j$ where f_L is the local oscillator frequency and f_i is the IF center frequency.

For each emitter in the valid signal band and each j-k spur band the distance and direction to the airborne EW system is computed from the emitter and aircraft locations and the received signal is computed from the emitter transmitter/antenna parameters and a propagation model. The signal amplitude at the mixer input is computed from the direction of arrival, the receiver antenna pattern and the receiver front end gain and filter characteristics. The signal amplitude at the IF port is then computed from the mixer transfer characteristic for the appropriate valid signal or j-k spur product.

For each emitter yielding a valid or spur signal at the IF port with amplitude greater than the detection threshold (referred to the IF port) the emitter PRF and pulse width are taken to form the valid signal and spur population parameters and compute the fractional loss of valid signals due to overlap.

The process is repeated for each frequency step. The step with the greatest fractional signal loss is identified for subsequent simulation.

WORST CASE CHANNEL SIMULATED SIGNAL SYNTHESIZER

A random number generator assigns a decimal fraction between 0 and 1 to each valid and spur emitter that represents the part of the pulse repetition interval that has elapsed at the start of the dwell. Based on the emitter pulse repetition interval that has elapsed at the start of the dwell. Based on the emitter pulse repetition frequency, the arrival time for each emitter pulse is computed. The pulse arrival times are sorted to determine the sequence of received pulses. Reseeding the random number generator assures that the selected sequence is typical. Associated with each pulse is its pulse width, IF frequency, computed amplitude and a set of computed interferometer phase differences based on direction of arrival.

From this simulation the number of pulses present at each instant of the dwell is determined so that a comparison with Poisson statistics may be obtained. Generally in the worst case dwell, the simulated signal consisting of the superposition of pulse trains from many emitters closely duplicates Poisson random pulse arrival statistical predictions.

The simulation provides the basis for the signal synthesizer (Figure 2). Let M be the number of interferometer phase differences so that the number of output signals is M+1, each feeding a separate receiver IF port. Let $\bar{N}$ be the largest number of pulses present at any instant during the dwell. The number, $N > \bar{N}$, of programmable signal sources is chosen (next section). Source j (j=1, 2....N) generates signals corresponding to pulses j+kN, where k=0,1,2 etc.

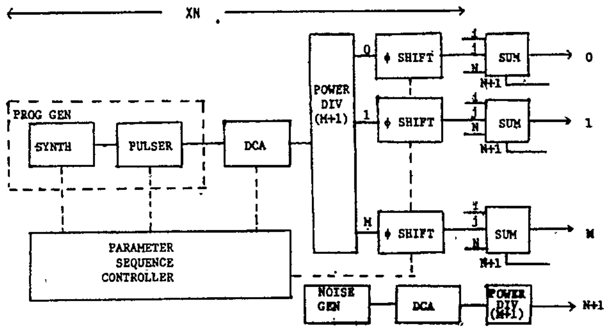

Figure 2: Programmable Signal Source

At the beginning of the dwell each source j(j-1,2...N) is programmed to the IF frequency and pulse width and triggered at the time defined by the simulation for pulse j. At the end of pulse j + kN (k-0,1,2..) source j is programmed to the IF frequency, pulse width and trigger instant defined for pulse j + (k+1)N.

Each source j(j=1,2,..N) output is set to the pulse j+kN(k=0,1,2..) signal level defined by the simulation by means of a separate digitally controlled attenuator that drives an M+1 way power divider. Each output i(i=0, 1..M) of the power divider is shifted in phase by means of a programmable phase shifter to generate a set of phase differences defined in the simulation for pulse j+kN.

Phase shifted outputs i for each source j, are summed in M+1 summers, each driving a separate IF port. Each summer has N+1 inputs, with N inputs derived from the programmed source and one input derived from a noise generator with prescribed signal level derived from the system noise figure at the frequency corresponding to the worst case dwell.

REQUIRED NUMBER, N, OF PROGRAMMABLE SIGNAL SOURCES

For a pulse population with Poisson arrival statistics, with arrival rate r, the waiting time, W, between pulse j time of arrival and pulse j+N+1 time of arrival has a Gamma probability distribution:

$$P_W(X) = P(W < X) = 1 - \exp(rx) \sum_{K=0}^{N} (rx)^K/K! \qquad (9)$$

If y is the mean pulse width and T is the time required to program the parameters for a pulse the probability that a set of N programmable signal sources will be insufficient to generate the required signals is equal to the probability that W< y + T:

$$P = P(W < y+T) = 1 - \exp\,[r(y+T)] \sum_{K=0}^{N} r(y+T)^K/K! \quad (10)$$

It is noted that P decreases with increasing N and decreasing r(y+T). Hence the required number of programmable assets to achieve a prescribed value of P decreases with r and y and as the programming interval T is shortened. An overall savings obtains through use of high speed direct synthesizers despite their relative complexity. For a given value of T the required number of assets, N, can be determined from the simulation by checking successive N pulse waiting times for different values of N.

CONCLUSIONS

The number of signal sources required to exercise the system signal processors is dramatically reduced (by two orders of magnitude) through use of programmable signal sources at IF. Detailed modeling of the antenna pattern, receiver front end and mixer is required to determine the spur population and the worst case channel. A separate simulation is thus required for each system under test. Nevertheless the described signal source can be made generic, applying to a broad spectrum of EW systems.

SAUL FAST

Mr. Fast is a McDonnell Douglas Fellow at McDonnell Aircraft Co., McDonnell Douglas Corp. Previous employment was at National Radio Co., Melrose, Mass (Vice President for Engineering. Prior employment was at W. L. Maxson Corp (Program Manager) and U.S. Army Electronics Research and Development Labs (Senior Project Engineer).

First single sideband receiver for U.S. Navy
First troposcatter system for U.S. Army
First Ionospheric Scatter system for U.S. Army
First 50 KW Power Amplifier for tropospheric scatter
First Tetrode Power Amplifier for tropospheric scatter system
First Troposcatter receiver solid state front end
First solid state diversity combiner
First 110 db dynamic range SSB
First single sideband receiver with drift cancelled loop synthesis
First Rake (anti-jam, anti multipath) receiver for U.S. Army
First receiver with parametric up-converter front end
First receiver with balanced quad diode front end
First solid state transmitter for radio relay use
First Airborne EW system with high speed electronically tuned receiver and radar jamming transmitter
First use of random look-through in phase locked receiver with frequency sweep acquisition
First microwave receiver/transmitter with all rf components broad-banded (1 octave)
First airborne solid statejammer (40 to 1 frequency range)
First isolating power amplifier coupler
First airborne jammer with 5 solid state HF-VHF transmitters on a common platform operating independently
First solid state broadband (HF-VHF) receiver coupler
First channelized receiver steering multiple assets
First Pulse Overlap Detection Circuit
Developed noise power ratio test for FDM radio relay intermodulation performance
Computer model for data bus multiplex to predict signal waveforms
Computer model for receiver to predict noise figure, intermodulation spurious responses and signal waveforms
Computer model for multiloop phase locked synthesizers to predict output noise spectrum, spurious output levels and acquisition time
Developed high speed computer algorithm for ambiguity resolution
Invented high speed sequential signal processor for pulse sorting
Invented phase lock loop that locks on desired weak signals in presence of 60 db stronger co-channel interference
Analysis for prediction of intermodulation performance of frequency division multiplexed (FDM) radio relays (thesis)

McDonnell Douglas Corp
Dept 313, Bldg 102/3/361
P.O. Box 516
St. Louis, Mo 63166
(314) 234-9718