IMPLEMENTATION OF TECHNIQUES FOR
DIGITAL REAL-TIME CONTROL OF AN R-F RADAR SIMULATION

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This paper describes a radar simulator that was conceived and developed at the Cornell Aeronautical Laboratory. The simulator provides, in real time, realistic radar problems including electronic counter measures effects as well as the normal radar echoes to radar operators. The simulator was designed to meet a requirement to simulate multiple penetrating aircraft using multiple penetration aids against multiple threat radars. That design goal was obtained. Even more satisfying is the great flexibility and realism achieved. These features can be credited mainly to the general purpose computer and its programs which control and react dynamically with the remainder of the simulator.

The simulator described herein was designed to test penetration techniques rather than to train people. Because of this difference in usage there are no doubt some areas where the simulator is either over or under designed as a training device. However, these differences are believed to be minor; indeed the simulator is used as a trainer in that radar operators must be brought to a high level of skill before they may be used in penetration tests.

The simulator consists of four major elements. First, a computer controls and interacts with the simulator. Next, interface equipment couples the computer with simulator hardware. An r-f signal generating system provides the received echoes and ECM signals. Finally, there are the radar receivers and consoles. Before considering these elements in detail, let us discuss some of the general features of the system.

Primary emphasis in design of the system was to achieve realism in the simulation and to provide very accurate quantification of all data. Thus a large dynamic range (95 Db) was designed into the equipment so as to match the real life situation. This range applies not only to signal levels but also to the description of parameters in the system such as antenna patterns and target cross sections. An accuracy of about 1 Db is maintained throughout the equipment. Other features such as scintillation of target echoes and dynamics of airplanes and radar antennas are incorporated.

The system provides all signals which would be received by the radar in a real-life situation. By time sharing the signal generators, it is possible to generate the signals for hundreds of targets in a typical test. The signals are generated at r-f in order to maintain realism of receiver front end effects in the simulator. Although S-band frequencies are incorporated in the system, any r-f frequency could be used. It was felt necessary to operate in an r-f environment rather than at video so as to permit the introduction of receivers into the system because it is difficult to define for simulation the non-linear effects of receivers on signals such as overload and intermodulation which can easily occur in an ECM environment. Further, by generating the signals at r-f, realistic mixing of signal and jamming and receiver noise is achieved - - a difficult if not impossible operation at video. From the trainer viewpoint, the incorporation of a receiver is very valuable because it allows the operator to train on all controls which would be available to him in a real-life situation, particularly any ECCM features such as Dicke-fix or IAGC. Finally, signal generation at r-f allows the ready use of real equipment. It would be quite simple

to package such a simulator in a van which could be moved from ship to ship and easily connected in to the r-f system of any of the radars aboard.

The general-purpose computer in the simulator provides a high degree of flexibility. For example, changing radars is a simple matter of punching a few cards to provide the new radar parameters such as power, prf and pulse width in the computer program. Of course, equipment changes in receiver bandwidth or console layout may be required. Likewise, new test plans or target characteristics are easily introduced into the computer program. By its very nature, the computer is an excellent device for accumulating test data and computing on-line results which are valuable in a training situation. For example, in tests against a Track-While-Scan (TWS) missile radar, a "Test Index" which measured the effectiveness of the radar operator in a jamming situation was displayed continuously.

Figure 162 is a block diagram of the simulator. The entire simulator is controlled by a general-purpose computer (an IBM 360/65) which stores radar, target, and jammer characteristics, and computes and keeps track of quantities such as radar pointing angle, target locations and aspect angles, and jammer antenna locations and angles. On a pulse-by-pulse basis, the 360/65 computes the frequency, pulse length, amplitude and time-of-arrival of each radar echo to each radar receiver. Signals such as broadband noise jamming and display triggers are generated in a similar fashion.
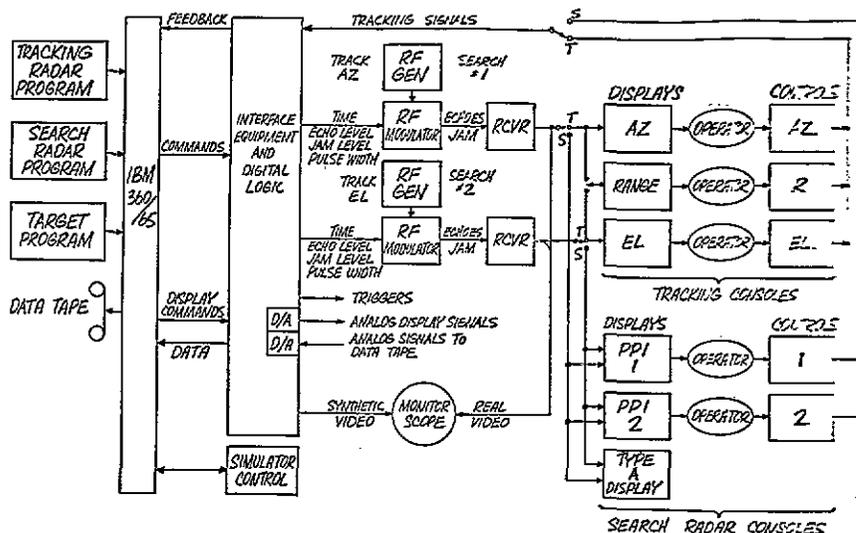

Figure 162. Block Diagram of Simulator

The computer was programmed in assembly language rather than a higher language (such as Fortran) in order to achieve a computing efficiency which allows the program to proceed in real time. Control of the simulator does not require all of the computer's capability in terms of computation time. The computer is, therefore, normally used on a time-sharing basis with other jobs, with the simulator having priority in order to maintain real-time operation. The computer program operates one time frame (typically one-tenth second) ahead of the real problem. After the computer has completed computation of a frame's worth of commands, it rests until the output of that frame begins. Typical duty cycle for the computer varies from a minimum

of about 15% to about 80% for a two-channel TWS radar and from about 1% to about 25% for a two-beam air-search radar. These upper percentages apply to problems which saturated the operators, and involved some 10 airplanes with multiple ECM transmitters in the TWS case and hundreds in the air search case. There have been a few cases in which the computer became saturated but these have not proven to be critical. The program is arranged so that low priority requirements such as data storage may be delayed for a frame to two if necessary in order to keep up with the main problem. With slightly more saturation, the computer repeats the last time frame to the simulator; these repeats are not noticed by the operator unless they occur on most of the frames.

The primary computer program is concerned with flying target aircraft and computing the characteristics of all received signals on the basis of the radar equation and ECM transmissions. An auxiliary function is to record data and compute results such as test indices. A test assembler for the preparation of tests has been programmed. System parameters of the system, such as radar and aircraft characteristics, are usually introduced only once into the main program. Following this, any number of tests may be introduced into the computer and called up at random. The data for these tests include the actions of the targets, such as aircraft flight paths and their ECM actions. Airplanes may be flown either by heading control or check point flying. Usually these test plans for the aircraft are prearranged, but external real-time manual control may also be exercised. The radar actions are not included in the test plan because the radar is always under control of the operators.

Many effects that are valuable for training purposes but which are not true to life can be controlled from the computer. For example, if a student were hopelessly lost in an ECM environment, it is quite easy to turn off the ECM or to momentarily bloom the target in order to re-orient him. Similarly, the level of the ECM environment is easily adjusted to adapt to the student's level of training.

One of the problems in developing the computer program was achieving the generation of signal commands in their proper time sequence and in an efficient manner. The present solution is to range order all targets once per frame. Then, beginning with the closest target, the commands for all of the echoes within a blip are computed. These commands are stored in a buffer matrix, and the commands for the next target in range order are computed and stored "behind" the commands for the closest blip. In this way, the time-sorting of commands within each sweep is accomplished at essentially negligible cost in computing time.

The output of the computer is a series of digital words which contain the information on time-of-arrival and signal characteristics (such as frequency and amplitude). These words or commands are fed to the Interface Equipment which connects the computer to the simulator. These commands can be transferred at an average rate (a limitation of the computer output device) of once per ten microseconds or one signal every radar mile. As signals may occur more closely spaced, it is necessary to provide a speed-up buffer in the interface so that targets may be accumulated in advance. The peak output rate of this buffer is 4 MHz or one signal every 125 feet. These numbers also represent the present timing accuracy or range granularity of the system. In the case where two echoes exist simultaneously the stronger of the two is painted. There are alternate solutions to the problem of what to do with overlapping echoes. One would be to compute in the computer the effects of the r-f beating between the two targets and to command the envelope signal.

Jamming from multiple noise sources is handled in a different manner. The computer calculates the contribution to each sweep from each jammer. These contributions are added for each sweep, and the total jamming level is commanded for each sweep.

A local clock in the interface times the execution of each command word from the computer. At the time of execution, analog and digital signals are generated which control the signal generators and the displays. A few of these control signals (such as for frequency and power level) are generated about one microsecond in advance in order to allow the controlled devices time to settle.

The interface equipment (Figure 163) also has auxiliary functions such as handling signals from operator controls, driving displays and recorders, and buffering data into the computer. Controls are available for starting and stopping tests, controlling ECM and targets, and for requesting the display of information from the computer. The computer at all times has complete knowledge of the changing test conditions, so it is a simple matter for the computer to provide on request data such as elapsed time, signal-to-noise ratio or jam-to-signal ratio of any target, target range and bearing, etc. Also, there is a monitor scope associated with the interface equipment on which can be displayed a repeat of the radar operator's scope or synthetic video without amplitude modulation or ECM.

The signal generator has two identical channels providing the signals for two radar channels. These channels can be independent and represent, for example, two beams of a radar system.

The r-f signal generator consists of a frequency controlled oscillator, an r-f switch to gate the oscillator and establish pulse width, and a PIN diode modulator to establish signal level. Noise-type signals are derived from a TWT noise source with their level controlled by another PIN diode modulator on a sweep-by-sweep basis. Pulse and noise signals are added before transfer to the receiver. Precision attenuators and noise figure meters are used in the calibration of the equipment. Calibration is carried out in a semiautomatic manner. The computer steps through all power levels while the technician measures the output power at each step. This measured power is read into and stored in the computer for subsequent use. Thus, the computer takes into account nonlinearities in the r-f generating system such as are present particularly in the PIN diode modulators.

The receivers and radar consoles are generic to the types which have been simulated since the real equipment was not available. Figure 164 is a photo of the consoles for a Track-While-Scan radar. This radar has two fan beams; one is scanning an elevation sector while the other an azimuth sector. The consoles were adapted from Navy VL height indicators to give a "B" scope presentation. The left operator tracks in azimuth using either slue or rate controls at his right hand to keep the target centered on a vertical azimuth cursor. The right-hand operator performs a similar tracking function in the elevation plane. The center operator tracks in range selecting video from either the azimuth or elevation beam.

The displays cover an angular extent of 20°. In the range coordinate the extent may be either 100 KM or 50 KM, or an expanded (5 KM) about the range tracking point.

Any operation of the antenna controls is transmitted to the computer which reacts and produces a corresponding change in the displayed signals. Other controls such as receiver gain and IAGC affect only the receiver but are transmitted to the computer for recording to facilitate subsequent data reduction and analysis.
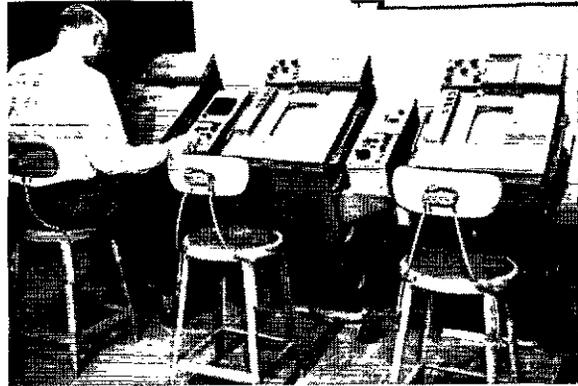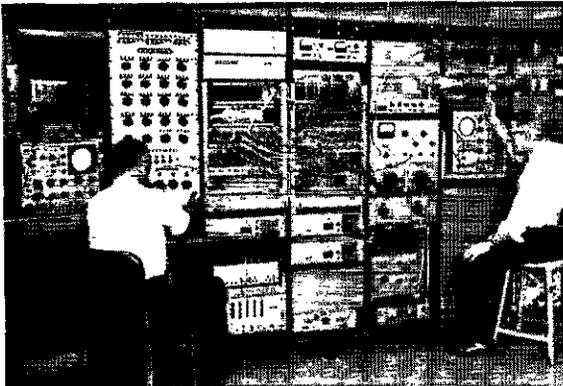
Figure 163. Interface and R-F Equipment Figure 164. Track-While-Scan Radar Consoles

Figure 165 contains snapshots from a movie which will be presented at the NTDC/Industry Conference. Figure 165a is a photo of a "B" scope without ECM. The two columns of targets are spaced at range increments to produce signals decreasing by 6 db decrements with range. The left set of targets have a cross section of 1 square meter; the other set are all 10 square meters plus one 10 square meter target at close range to show antenna side lobes.

Figure 165b contains three aircraft plus a noise jamming strobe from a fourth aircraft at a range beyond the display. Figure 165c follows Figure 165b in time and contains a second noise strobe from a self-screening jammer on one of the planes visible in Figure 165b. Figure 165d is again later in time and contains a third jamming strobe. The fainter strobes are jamming entering the side-lobes of the radar antenna. Unfortunately these still photographs cannot illustrate the dynamics of the simulation such as target scintillation, moving targets, background noise and jamming.

Figure 166 is a photo of two consoles for an air-search radar. Again the consoles are generic using Navy SPA-8 PPI indicators. The operators at such indicators would normally be using a grease pencil which cannot be monitored by the computer. In its place an electronic "grease pencil" was instrumented by painting a tracking dot on the scope. A track history is maintained on the scope by flashing in sequence the last five dots, with the lead or latest tracking dot solid or nonflashing. Controls at the left of the console allow the operator to sequence between targets, kill tracks, start new tracks, and tell the computer whether he thinks he is tracking a target or jamming strobe. Each console is driven from its own signal generator and receiver. Thus the system may represent two different beams of a stacked beam radar or allow two operators to be trained independently on the same beam. Two quite different radars have been simulated at these consoles. One radar had six beams stacked vertically. A control at the upper left of the console allows the operator to select any specific beam. By means of another knob, he may also mix any amount of video from his partner's scope. Because each beam was at a different elevation angle and a different frequency, the display of targets and ECM from beam to beam was very different. Although the computer kept up to date on the action in each beam it was necessary to compute the signals only in the displayed beams.
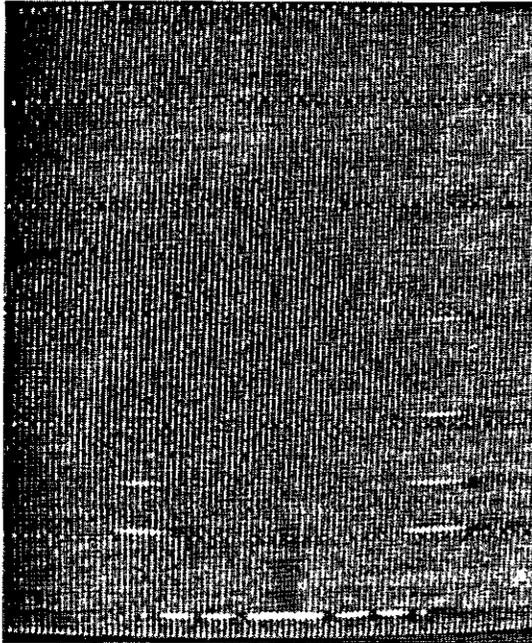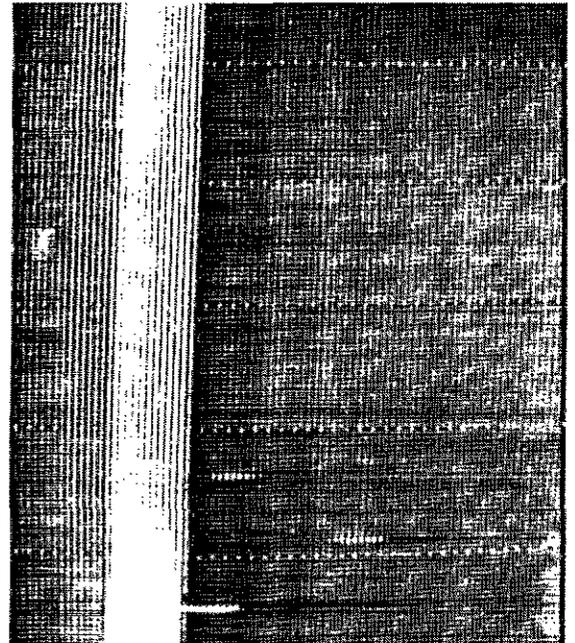
Figure 165.   Photographs of B-Scope

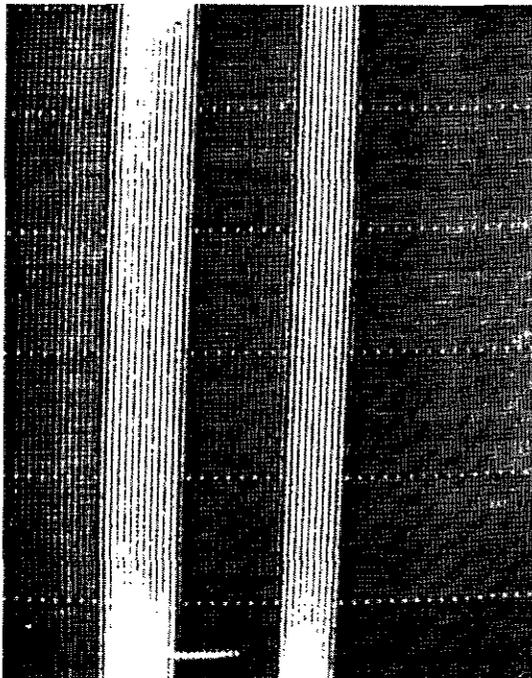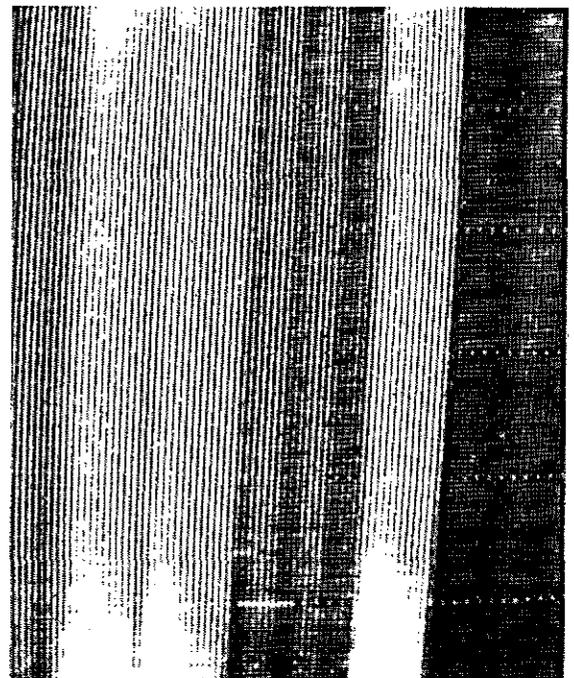Figure 165a.
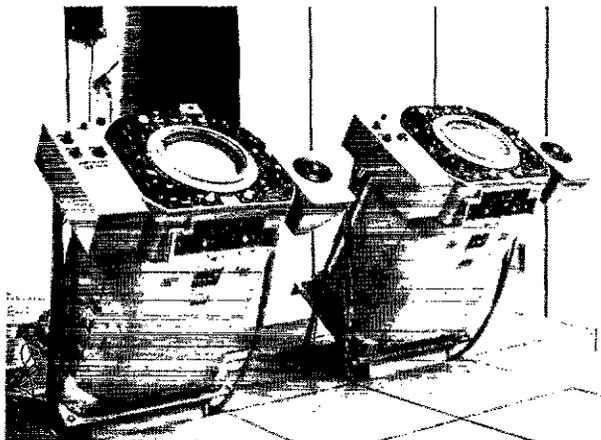
Figure 165b.

Figure 165c.

Figure 165d.

Figure 166.   Air-Search Radar Consoles

The movie shown earlier illustrated a few of the types of targets and ECM which have been simulated. The actual inventory is quite large but cannot be discussed in the open literature. However, there are two major classes - - clutter and chaff - - which have not been completely simulated. A limited amount can be and has been introduced by generating signals for individual resolution cells. The computer I/O channel is the limiting factor. For large area painting of chaff or clutter it appears necessary to rely on the computer for a gross description of the area with auxiliary external equipment to define details within the area.

SUMMARY

The radar simulator that has been described in this paper has proven to be a very versatile means for realistic simulation of a large variety of tactical situations involving electromagnetic environments. Most situations and equipments can be simulated by introducing the proper parameters and descriptors into a general purpose computer. As necessary, receiver and display modifications are also involved.

Realism was achieved by careful attention to the programming of radar effects such as scintillation and by overall design which incorporates a large dynamic range with precise calibration. The digital computer is the major contribution to the success of this technique. It provides precision exceeding that obtainable from analog equipment.