Digital systems for array radar

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INTRODUCTION

The purpose of this paper is to present the role and philosophy of digital techniques, and especially of general purpose digital computers, in array radar systems.

Array radars and digital computers are extraordinarily well suited to each other. The flexibility and high data rate available from multibeam, multifunction array radars require an equally flexible, equally fast controller—a general purpose digital computer. The beam steering for many types of array radars is of a digital nature; and, of course, range, doppler frequency, and other quantities are inherently digital (after the information is extracted from the signal) just as in conventional radar.

The characteristics of digital computers that make them useful in a radar system are:

Perfect Memory: Digital memories can retain information with no loss in accuracy.

Time-sharing: The digital equipment is time-shared among many functions. This reduces system complexity and cost.

Decision-making ability: The logical design and digital nature of computers facilitates decision making.

Precision: Precision can be obtained as a linear function of cost.

Reliability: Digital computers can be among the most reliable subsystems of a radar.

A fully integrated digital controller and data processor can be implemented using a general purpose digital computer, in which all controller functions time-share the computer. This places a severe speed and reliability requirement on the computer, but off-the-shelf equipment is available to satisfy many present radar system requirements. The functions of a large scale array radar which can be integrated into the computer are:

• Radar control
  Search raster generation
  Beam steering
  Range gating
  Transmitter and receiver frequency

• Radar data processing
  Detection rules
  Track initiation
  Range and angle tracking
  Coasting
  Target identification
  Track-while-scan

• Radar monitoring
• Display processing
• Console data processing
• Logistics
• Radar evaluation
• Radar checkout

Typical system configuration

An example of a digital system for an array radar is shown in block diagram form in Figure 1. This diagram and most of the following discussion are a hypothetical composite drawn from several projects in current development.

In systems where great flexibility is required, and where events may be separated by time intervals shorter than the Input/Output transfer time, a Radar Instruction Buffer storage and timing unit has been used.

The computer sends ordered instructions (for the radar to execute) to the Radar Instruction Buffer; each instruction has a time tag to specify its time of execution. These instructions might be:

• Steer the transmitter to angular coordinates A and B.
• Send Pulse P, at time Time,.
• Steer the track receiver beam to angular coordinates A and B.
• Range gate the signal at time T,.

These instructions are held in the Radar Instruction Buffer, are decoded, and are gated to the proper equipment at the proper time to initiate the desired function.

The return signals are gathered by the receiver antenna and pass through the receiver, video con-
The computer accesses test points in the radar via the monitoring equipment, and encodes the information for that test point in digital form for the computer. Provision is also made in the monitoring equipment for the computer to inject test signals when required for calibration and monitoring.

Manual control information from the Operations Control console is sent to the computer which translates the control information into radar instructions, adds timing information, and sends the instructions to the Radar Instruction Buffer. The computer also processes and formats information for display, and it can change the displayed information at the request of the operator.

**Radar/computer interface**

Figure 2 is a block diagram of the Radar Instruction Buffer. This approach to the Radar/Computer Interface has been used on large systems. On simpler array radars this equipment is omitted, and the various radar subsystems are tied directly to computer I/O channels.

**Functions controlled**

The functions listed in Table I are typical of those functions which might be controlled in a large array radar.

<table>
<thead>
<tr>
<th>Function</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receiver converter</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Beam steering angles</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam width</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pulse time, duration</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pulse coding</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Range gate position duration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doppler filter range</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Coherent integration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calibration and monitoring</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Method of control**

The computer loads the Radar Instruction Buffer memory with a sequence of radar instructions. These instructions contain an address (equipment destination), time tag, and data. The instructions are loaded in time-ordered sequence. The Radar Instruction Buffer compares the time tag of the first instruction with its clock; when equality is reached, that instruction is sent to the designated address to initiate the function in real time. The next instruction is then loaded into the control.

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Figure 1 – Digital system for array radar functional block diagram

Figure 2 – Radar instruction buffer functional block diagram
output section where it is held until time equality is again reached.

The word length of instructions is determined by the number of events which must happen simultaneously, i.e., within the time to get one instruction from the Radar Instruction Buffer. For a multibeam tracking radar the word length must be quite large because of range gating and other signal processing requirements in the many beams. Many functions need not be critically timed except in very heavy target environments.

The monitoring information is requested through the Radar Instruction Buffer because of timing requirements. Some measurements must be made during dead time, some during active time; some require test signal injection and then read out at precisely controlled times.

**Radar data processing**

Radar data processing techniques for computer-controlled conventional radars have been thoroughly covered in the literature. The following discussion concerns the functions and the implementation rather than techniques.

**Functions**

The functions which have to be performed are:

- Search pattern generation
- Detection
- Track initiation
- Track-while-scan
- Range and angle tracking, smoothing, and extrapolation
- Automatic gain control
- Noise, sidelobe, and clutter rejection
- Video threshold determination
- Target identification
- Allocation of radar capacity

With a multifunction radar, all of these functions may have to be performed concurrently.

**Implementation**

The implementation of the above functions in an array radar is complicated by the flexibility of the radar. The use of the available pulses, time slots, and other radar capacities in an efficient manner requires a scheduling program which allocates the resources according to the target environment. A record must be kept of the allocation of pulses to targets so that as the returns are received the information can be sorted out, correlated with the proper tracks, or otherwise suitably processed. The result of this is that although the conventional basic computing algorithms are used for radar data processing, they require considerable additional program control logic in the array radar environment.

One of the largest uses of computer speed in radar data processing is the reduction of redundancy and randomness of radar signal tracking data, and this burden increases linearly with the tracking capacity of the system. The tasks which place the heaviest burden on the data processor are those done every cycle. Examples of these are:

- Range and angle tracking
- Pulse-to-pulse signal integration for detection
- Noise processing
- Automatic gain control
- Noise and sidelobe rejection

In a dense environment, even the fastest presently available stored-program computer may not have adequate speed. In this case, a wired-program processor may be used between the video converter and digital computer to perform the highly repetitive pulse-to-pulse correlation on the data. The correlation reduces the data rate (by reducing the redundancy) to a level where it can be handled by the stored-program computer. Development work is now proceeding to design advanced stored-program computers that are fast enough to process data from target densities substantially above present capability.

**Radar monitoring**

The large numbers of electronic components in array radars require a departure from manual methods of fault detection and diagnosis. The many repetitious circuits, which can be easily accessed by a computer, lend themselves to automated sampling and checking. In an automated Radar Monitoring subsystem the computer would perform the following tasks:

1. The computer sequences through all tests, sampling each test point at its required rate. The output of a signal channel is sampled relatively often to determine if the overall channel alignment is within limits. The component parts of a channel are sampled less often to determine if two components are drifting in compensating directions toward failure.

2. The computer commands the appropriate test signals, if required, via the Radar Instruction Buffer during the proper part of the radar cycle.

3. The computer examines the results of the test and takes appropriate action. If analysis of the failure indicates that it can be remedied by computer action, the computer performs the programmed corrective measures. If not, the maintenance man is notified by a message output.

If the failure cannot be localized to one least replaceable unit, further tests are performed, and the results are associatively processed to localize the failure to a least replaceable unit.
(4) The computer supplies instructions to the maintenance personnel. The radar is so complex that available maintenance personnel will be limited in their ability to diagnose failures or to take proper corrective action.

(5) The computer services maintenance personnel messages to the computer. These include:
- A request for special test so the maintenance man can locally adjust components or diagnose failures with test equipment.
- A notice that a failed component has been replaced or adjusted.
- A list of all components likely to fail in the next time period.
- A list of all components that exceed a certain margin.

(6) The computer assists the maintenance personnel in preventive maintenance by notification when timely replacement of components is required, or failure is imminent.

(7) The computer records component failure and replacement information for reliability and logistics purposes. The current failure information is used to estimate the degradation of radar performance; this information is provided to the Maintenance Console and Operations Control Console.

Display and control

Although computer-controlled radars are capable of fully automatic operation, displays are necessary for the radar operator to monitor the system operation. In addition, controls must be available to provide manual control of the radar. In conventional radars the received signals can be displayed directly on a cathode ray tube because the beam is moved in a regular pattern. In an array radar the time-sharing of the beam among many functions requires that display and control be carried out through the computer.

In dense target environments the computer distributes the information to several operators according to task and workload. Since computer-driven displays are largely general-purpose, the equipment can be designed or obtained before its precise method of use has been decided. Computer-driven displays can provide summarized or derived quantities which are much more useful than raw data. Examples of these quantities are:
- Bearing angle
- Impact point
- Distance of closest approach
- Radar cross-section

The following display and control description illustrates the requirements of an array radar system.

Operations control console

The Operations Control Console has two functions:
1. Displays
   - The displays include:
     - A-scope
     - Azimuth vs. elevation digital CRT display
     - Alphanumeric digital CRT display
     - Azimuth vs. range digital CRT display
     - Special purpose status indications
     - Medium speed printer

   The A-scope is used to present targets in a beam, but not necessarily in track, and can be manually switched to any beam. The A-scope is triggered by the computer, but the trigger can be modified in position and velocity from the console.

   The azimuth vs. elevation scope has characters displayed on it by the computer to show the location and status of tracks.

   The azimuth vs. range scope similarly has characters displayed on it by the computer to show the location and status of tracks.

   The alphanumeric scope is used to display operational data (for any target designated by the operator) such as:
   - Track status
   - Position, velocity
   - Target identity
   - Altitude
   - Distance to nearest object
   - Signal to noise ratio

   It also displays information, for the radar as a whole, such as:
   - Number of objects in track-while-scan
   - Number of objects in precision track
   - Per cent of traffic capability being used

2. Controls
   - The Operations Control Console has the following controls:
     - Mode control (auto, trim, manual)
     - Cursor/light gun for each CRT display
     - Range and range rate trim, scale adjustment, and beam selector on A-scope
3. Operation
The radar system has three modes of operation: automatic, trim, and manual. In automatic, the operator can request information and alternate procedures, but has no direct control over the radar. For example, the operator could request to have displayed numerically the position, velocity, time of arrival, radar cross section, and orbital parameters of a target. Examples of other requests he could make are:

- To see video on a particular track.
- That a particular target be put in precision track.
- That the false alarm threshold be changed.
- That the search boundaries be changed.

In the trim mode the operator has all functions of automatic mode, and in addition can manually modify the steering of the beam and the range gates. This mode is used to let the operator assist the radar in abnormal situations.

In the manual mode the operator assumes complete control and must supply all parameters to the radar. The computer protects the radar from damage by operator error. This mode is used for checkout, special test, and diagnosis of faults.

The cursor or light gun allows the operator to designate targets for action or information.

Monitoring console
The Monitoring console has two functions:

1. Display
The Monitoring Console will display information concerning the transmitter, receiver, and video converter. It will consist of:

- General purpose CRT
- Keyboard
- Medium speed printer
A high speed printer will be available for printing large amounts of data.

2. Operation
The operator may request the following displays on the CRT and/or printer by typing in the appropriate message on the keyboard. In the following, “component” refers to the smallest testable unit.

- Display in their proper spatial relation all transmitting or receiving antenna elements that are out of tolerance.
- Display (list) any one of the items in Table II. In addition, the operator will be able to request special radar tests and results via the keyboard.

<table>
<thead>
<tr>
<th>Display quantity</th>
<th>1 Transm Receiver</th>
<th>2 Receiver converter</th>
<th>3 Video converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of channels out</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>First moment of outages</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Peak power (sensitivity) available</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
</tr>
<tr>
<td>Function outages</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Redundant components out</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Estimated angular accuracy</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Estimated statistical sidelobe level</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>All failed or out-of-tolerance components</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Signal path with poorest performance</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Component with least margin or adjustment</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>All signal channels within X of failing</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>All components within X of failing</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Histograms of component tolerances</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Histograms of channel tolerances</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Histogram of percent adjusting remaining</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>All failed channels and components</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>All components requiring manual adjustment</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>All components at limit of automatic adjustment</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Logistics
A large scale array radar system may have spare parts inventories of several thousand items. Many of
these items have long lead times and require that the reordering point be determined as a function of the usage rate and required lead time. The computer has most of the data required to maintain spare parts inventory records from the monitoring and parts replacement information. Since the computer is rarely in a full-load condition, the reserve computing capacity can be used to maintain logistics information on a low priority basis at little extra cost. The automating of this function will reduce the manpower requirements and cost for maintenance.

**Functions**
The following logistic functions would be performed:
- Maintain spare parts inventory.
  - Issue reorder requests based on lead time and usage rate for each item.
- Maintain reliability records for failure rate, drive rate, frequency of adjustment required, mean time to failure, and mean time to repair.

**Implementation**
In normal monitoring operation, all manual adjustments, failures, and parts replacement information are recorded on magnetic tape. New supplies from the manufacturer or repair depot are recorded on punched cards, and this information, together with the monitoring data, is used to update the spare parts inventory periodically.

Where applicable, drift rates are computed from monitoring information and used to modify the reorder point and to predict end-of-life failures.

The statistical summaries on drift rate, time to failure, time to adjustment for each component and the system are also derived from the monitoring data.

**Simulation**
Real time simulation of operational situations can be performed by the central computer. The simulation can be done with artificial data generated within the computer, or it can be done by replaying digitally recorded data from real missions. This replay capability is very important in post mission analysis where considerably more information is recorded than can be displayed in real time. During the simulation, the displays and various other equipment are activated, depending on the purpose.

Simulations which involve the displays are used to train operators and to maintain their proficiency in situations encountered infrequently. It also simulates malfunctions to exercise maintenance personnel.

Simulations also provide realistic data to check and evaluate parts of the system equipment and programs.

**Checkout and evaluation**
The computer can be very useful in the checkout and evaluation of each subsystem before it goes into the radar, and of the entire radar system once it is operational. Any complex piece of equipment requires a formal checkout procedure to verify its correct operation. If these checkout procedures are implemented on a computer during the manufacture of the equipment, then the diagnosis and location of faults can be done quickly. These checkout programs are very similar to the usual fault detection and diagnosis programs that are supplied to maintain equipment, and can often be obtained for little additional cost.

**CONCLUSION**
The preceding paragraphs have presented the role of general purpose digital computers in array systems. The topics discussed were:
- Advantages of digital computers
- Data processor system configuration
- Control of radar
- Radar data processing
- Radar equipment monitoring
- Radar-computer interface
- Computer support for display and control
- Computer support of logistics
- Simulation of system operation
- Program organization
- Checkout and evaluation assisted by computer

Computers have proven themselves to be highly useful members of array radar systems in performing the tasks assigned to them. As the capability of digital data systems equipment and programming continues to increase, it is reasonable to expect that the role of computers in array radars will continue to increase.