FAA-73-34

REPORT NO. FAA-RD-74-65

ARTS III COMPUTER SYSTEMS PERFORMANCE MEASUREMENT PROTOTYPE IMPLEMENTATION

H.J. Glynn
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APRIL 1974
FINAL REPORT

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Prepared for
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research and Development Service
Washington DC 20590

Technical Report Documentation Page

1. Report No.
FAA-RD-74-65

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
ARTS III COMPUTER SYSTEMS PERFORMANCE MEASUREMENT PROTOTYPE IMPLEMENTATION

5. Report Date
April 1974

6. Performing Organization Code

7. Author(s)
H.J. Glynn and F.J. Woolfall

8. Performing Organization Report No.
DOT-TSC-FAA-73-34

9. Performing Organization Name and Address
Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

10. Work Unit No. (TRAIS)
FA-403/R-4109

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Department of Transportation
Federal Aviation Administration
Systems Research and Development Service
Washington DC 20590

13. Type of Report and Period Covered
Final Report
July 1971 - Nov. 1973

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Implementation of prototype software-measurement tools as applied to the ARTS III Single Beacon Tracking Level System is presented. Evaluation of these tools provides the foundation for recommendations of specific performance measurement tools regarding ARTS III Single and Dual Beacon Systems:

Section 1: Introduces the study program, states the objectives, and enumerates the program's accomplishments.
Sections 2 and 3: Describe the ARTS III System and the ARTS III Operational Program, respectively.
Section 4: Contains an examination of performance-measurement monitors.
Section 5: Defines the prototype measurement tools.
Section 6: Contains a preliminary analysis of measurement data.
Section 7: Evaluates the prototype measurement tools and the impact of these tools on ARTS III.
Section 8: Contains the summary and recommendations.

17. Key Words
Measurement Computer;
Monitor Sampler;
Data-Processing, ARTS III

18. Distribution Statement
"APPROVED FOR FAA USE ONLY. THE DOCUMENT IS EXEMPTED FROM PUBLIC AVAILABILITY BECAUSE THE REPORT IS BASED ON DATA USING AN ARTS OPERATIONAL PROGRAM THAT HAS BEEN SUPERSEDED. IN ADDITION, THE SURVEYS ON THE HARDWARE, SOFTWARE, AND HYBRID MONITORS WERE BASED ON DATA WHICH DOES NOT TAKE INTO ACCOUNT MORE RECENT DEVELOPMENTS IN THESE AREAS. TRANSMITTAL OF THE DOCUMENT OUTSIDE THE FAA, DEPARTMENT OF TRANSPORTATION, MUST HAVE PRIOR APPROVAL OF THE FAA, SYSTEMS RESEARCH AND DEVELOPMENT SERVICE, 2100 SECOND STREET, S.W., WASHINGTON, D.C. 20590."

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The work described here was performed as part of an overall effort to investigate the application of Computer System Performance Measurement technology to automated Air-Traffic Control.

Prototype software-measurement tools were implemented on the ARTS III Test Bid Facility in Minneapolis MN and integrated into the ARTS III Single Beacon Operational Program (OP-05). Data reduction and graphical-representation programs were developed in house.

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GLOSSARY

ACP	azimuth change pulse
AM	flight plan amendment message
A/N	alphanumeric
AOFSTIL	automatic offset module label
APG	azimuth pulse generator
ARP	azimuth reference pulse
ARTCC	Air Route Traffic Control Center
ARTG	azimuth range and timing group
ARTS III	Automated Radar Terminal System III
ASR	airport surveillance radar
BCW	buffer control word
BRG	beacon reply group
BUFFI	software label referencing buffer 1
BUFFII	software label referencing buffer 2
CPSE	display output chain preparation module label
CPU	central processing unit
COMMSR	common subroutines module label
CRT	cathode-ray tube
CTS	central track store
CTYPX	console typewriter output module label
CX	cancellation message
DA	no error detected
DAS	data acquisition subsystem
DATAEXT	data extraction replies label
DC	District of Columbia
DEDS	data entry and display subsystem
DM	departure message
DPEEXF	data extraction module label
DPS	data processing subsystem
DOT	Department of Transportation
DR	error detected, retransmit
DT	test response
DX	error detected, do not retransmit

GLOSSARY (CONT'D)

EBCDIC	extended binary coded decimal interchange codes
EFW	external function word
EM	emergency
ENCHIN	enroute interrupt routine
ENINTC	interfacility interrupt routine
ENRINC	interfacility input processor
ENROTC	interfacility output module label
EOM	end of message
ETA	estimated time of arrival
EXAOM	executive program time flags table
EXEC	executive routine label
FAA	Federal Aviation Administration
FDB	full data block
FPM	flight plan message
GFE	government furnished equipemnt
ICA	intercommunication adapter
I/O	input/output
IOP	input output processor
IOSTOP	IOP command used to terminate a sequence of chained I/O commands
IX-7	index register 7
JUMP KEY	reference a jump condition key exercised for measurement runs
KIPZ	keyboard input processor module label
KOFK	keyboard operational functions module label
LBJ	load index register and jump instruction mnemonic
LRC	longitudinal redundacy check
MA	Massachusetts
MN	Minnesota
MTFPY	magnetic tape flight plan input module label
MTINTY	magnetic tape interrupt routine label
MTIPF	potter interrupt routine label
MTI6CF	VI-C interrupt routine label
MTS	magnetic tape system

GLOSSARY (CONT'D)

NAFEC	National Aviation Facilities Experiment Center
OP	operational program
PPI	plan position indicator display
PRF	pulse repetition frequency
PRINT	core dump routine label
PTD	proposed time of departure
PUB	process unused beacon
PWTIC	power failure restart module label
RF	radio failure
RJ	return jump instruction mnemonic
RTC	real time clock
SFAPTS	target generator module label
STOPE	system timeout processing module label
TA	track accept message
TI	track initiate message
TIMER	operational program timing routine
TM$E	executive timer label
TR	test message
TRACKB	beacon tracking module label
TSC	Transportation Systems Center
TU	track update message
VI-C	uniservo magnetic tape drives

1. INTRODUCTION AND OBJECTIVES

1.1 INTRODUCTION

This report documents the implementation of prototype software-measurement tools as applied to the ARTS III Single Beacon Tracking Level System. The implementation is part of the entire effort defined in the Project Plan Agreement between the Transportation Systems Center (TSC) and Federal Aviation Administration (FRA), "Advanced Computer Systems Techniques," the objectives of which are to develop approaches to design problems of the complex hardware/software systems required for fourth-generation air-traffic control systems.

Although the main thrust of the report deals with prototype software-measurement tools, ARTS III hardware and software design features are highlighted in sections 2 and 3. Section 4 contains a description of performance measurement monitors.

Section 5 describes the prototype software-measurement tools developed. These tools were debugged and exercised at the ARTS III Test-Bed Facility, Minneapolis MN.

Preliminary analysis of the measurements obtained is discussed in section 6. The measurement tools are evaluated in section 7. Section 8 summarizes the major facets of prototype measurement implementation, and suggests certain improvements for upgrading the measurement tools toward pre-operational status.

1.2 OBJECTIVES

The principal objectives of the overall study are:

a. Define appropriate performance-measurement tools for the ARTS III Single-Beacon Tracking Level System.

b. Establish hardware/software requirements and specifications for the application of these performance-measurement tools.

In support of these objectives, both TSC[1] and the Lambda Corporation[2] have performed work in five major areas:

1) Evaluated existing computer performance-measurement tools.

2) Examined the basic ARTS III Single-Beacon Tracking Level System.

3) Examined the applicability of existing measurement tools to the basic ARTS III system.

4) Developed prototype software-measurement tools.

5) Exercised these tools on a version of the ARTS III at the ARTS Test-Bed Facility in Minneapolis MN.

1.3 ACCOMPLISHMENTS

As a result of the work performed in the aforementioned five major areas of the study, the following objectives were realized:

a. A pre-operational Sampler Monitor and a Hardware Monitor for the Basic ARTS III Single-Beacon System have been defined (see sections 8.2.1 and 8.2.2).

b. Software requirements and specifications for the application of the Sampler Monitor have been established (see section 8.2).

c. A list of items to be considered in procuring a hardware monitor are contained in reference 3 of this report.

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[1]Gertler, J., H. Glynn, V. Hobbs, and F. Woolfall, Computer Systems Performance Measurement Techniques, Technical Report, DOT-TSC-FAA-71-23, FAA-RD-123, June 30, 1971.

[2]King, L., Report on ATC Computer Systems Performance Measurement Study, Lambda Corp., Technical Report DOT-TSC-106, March 15, 1972 Arlington VA, Rev. July 1972.

[3]Hobbs, V. and J. Gertler, "Computer System Performance Measurement Techniques for ARTS III Computer Systems", Final Report DOT-TSC-FAA-73-22, FAA-RD-73-195, December 1973.

2. ARTS III SYSTEM DESCRIPTION[4]

2.1 ORGANIZATION

The basic ARTS III Single-Beacon Tracking Level System is shown in figure 2-1. The Data Acquisition Subsystem (DAS) receives beacon video from the Beacon Interrogator, detects and digitizes beacon-code trains, and transmits the digitized replies to the Data Processing Subsystem (DPS). The DAS also provides partially decoded beacon video to the Data Entry and Display Subsystem (DEDS).

The DPS is a high-speed microelectronic digital processor which performs input/output (I/O) control and data processing functions. Console Typewriters and a Magnetic-Tape unit are standard I/O peripheral equipment at all ARTS III installations.

The DEDS is the man/machine interface between the air-traffic controller and the ARTS III. As many as ten DEDS consoles can be used in a single beacon display system. The console contains as many as three sets of data entry devices. Each device consists of (1) an alphanumeric (A/N) keyboard, (2) a trackball for target acquisition, (3) field inhibit switches to delete information, and (4) five quick-look switches to observe data being displayed at another selected console position.

2.2 DATA-ACQUISITION SUBSYSTEM

The DAS is shown in figure 2-2. The Azimuth Range and Timing Group (ARTG) generates synchronous range, azimuth, and control pulses, and examines beacon-mode pulse pairs from the Beacon Interrogator. If a Mode 3/A or Mode C beacon is being interrogated, the ARTG activates the Beacon Reply Group (BRG). The BRG extracts the beacon-code data from the beacon replies and generates range-synchronous pulses for the DEDS PPI display

[4]Sperry Rand, Beacon Tracking Level System Copy, UNIVAC PX6213 Rqmt., St. Paul MN, October 1971, Section 2, System Description In: General System Manual for ARTS III

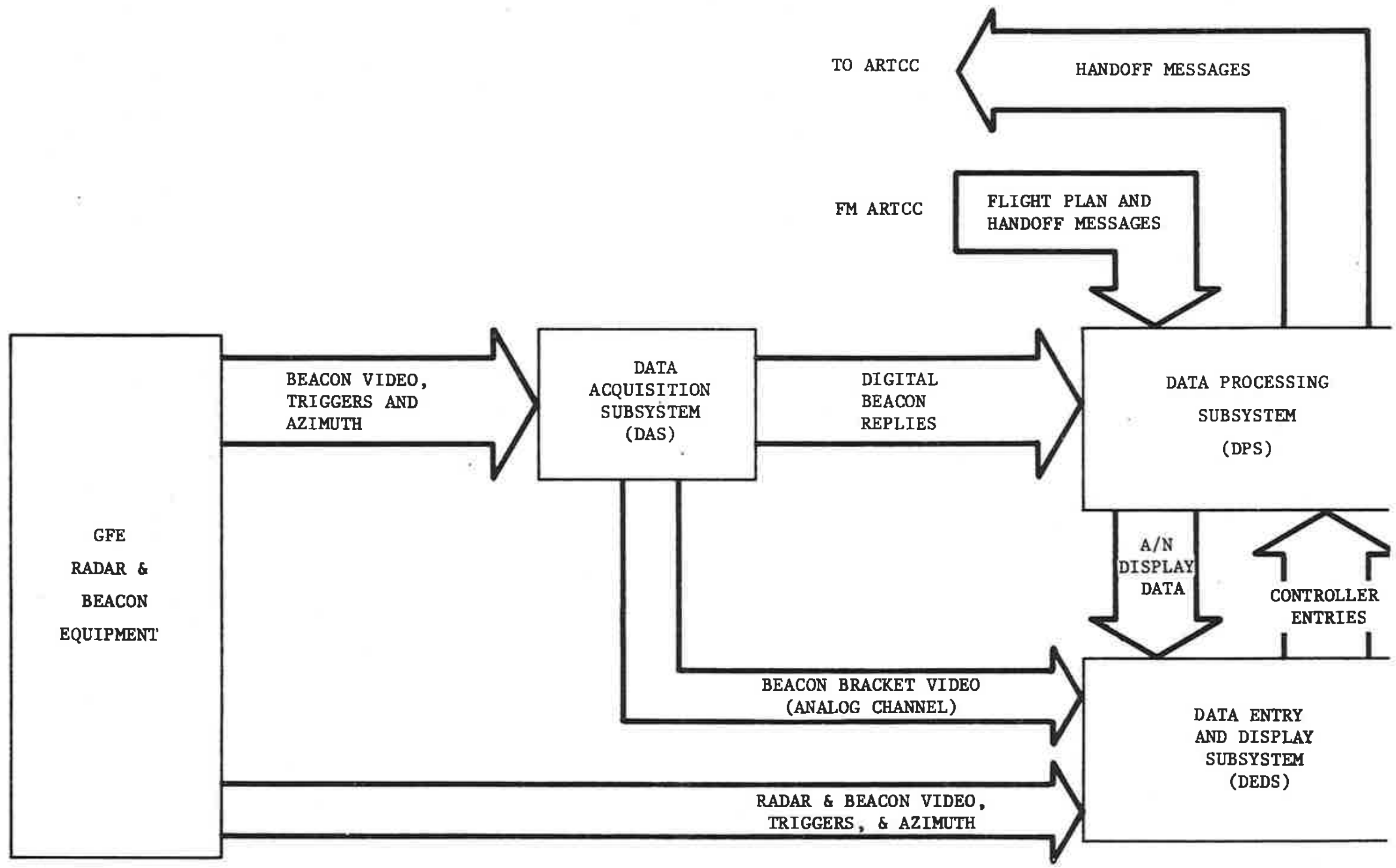


Figure 2-1. ARTS III Single Beacon-Tracking Level Block Diagram

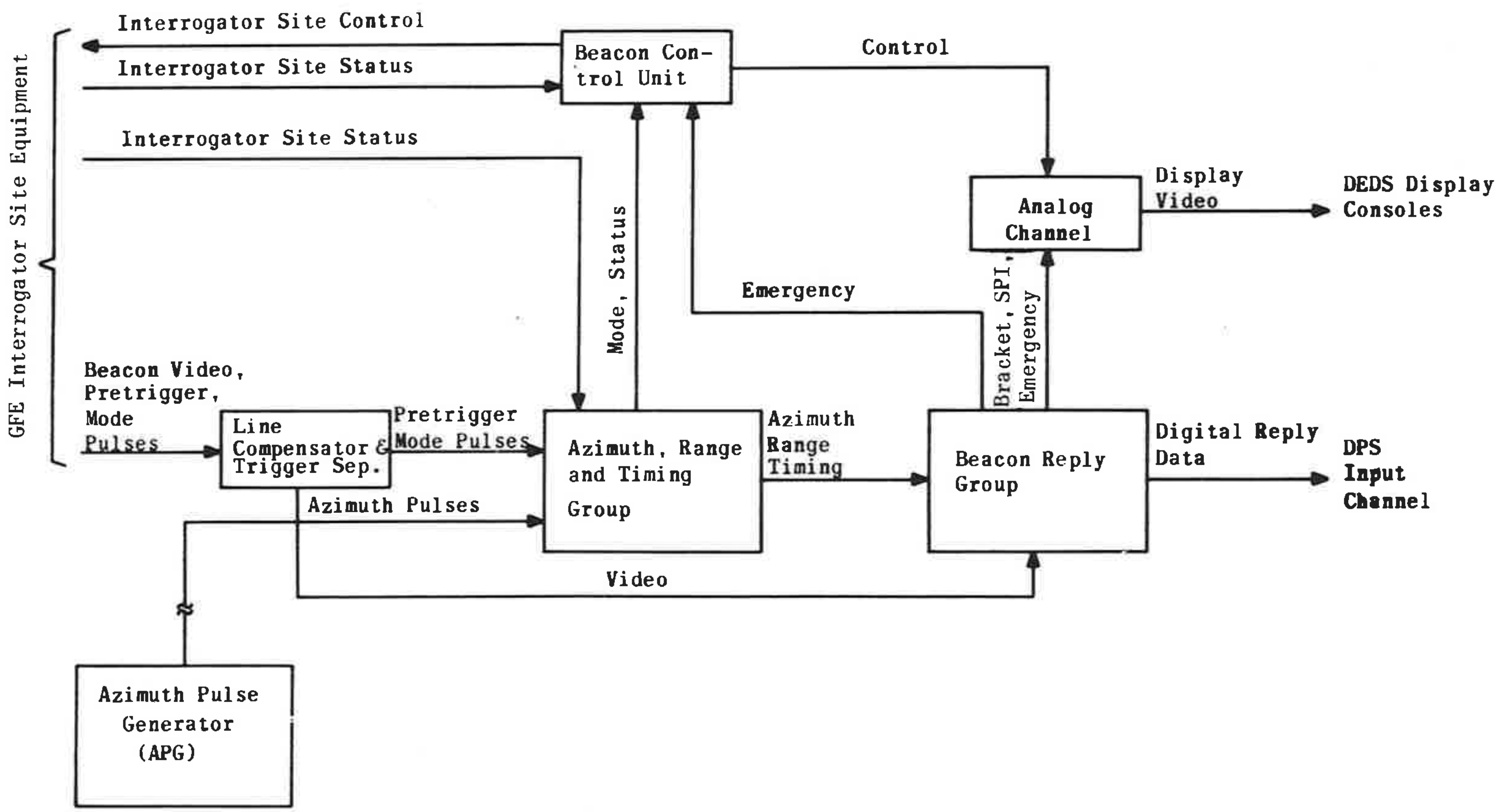


Figure 2-2. DAS Block Diagram

or each detected reply. The code data are made available to the DPS for further processing. The Azimuth Pulse Generator is a photo-optical shaft-position encoder which is antenna-mounted at the airport surveillance radar (ASR). The encoder generates 4096 Azimuth Change Pulses (ACPs) and one Aximuth Reference Pulse (ARP) for 360 degrees of antenna rotation. The ACPs and ARP synchronize the ARTG outputs that are applied throughout the ARTS III.

2.3 DATA-PROCESSING SUBSYSTEM

The DPS consists of an Input/Output Processor (IOP), Memory Modules, Peripheral Adapter Module, and peripheral equipment. A single-beacon ARTS III site configuration is shown in figure 2-3.

This site configuration does not support program development or any conventional utility operation, such as program assembly, call linkage, or core dump or tape operations. The ARTS III Support Software System, however, operated in a Program Generation Configuration to perform these essential functions. This configuration contains, in addition to the basic equipment of the terminal system, four Uniservo tape units, a UNIVAC 9300 performing as a card reader, and a high-speed printer. The configuration allows development of programs, from assembly through form conversion to loading, and supports a full range of utility operations. In addition, the interface with DEDS and DAS gives the system an operational capability for extensive testing and debugging.

The Program Generation System utilized for testing and evaluation performed in the study report here is represented in figure 2-4.

Salient features of the IOP include:

- o Access to the data channels,
- o Access to core memory, addressable in 30-bit words,
- o A 30-bit accumulator register A,
- o A 30-bit quotient register Q,
- o Eight 30-bit indexing registers BO,B1,...,B7,
- o Three 5-bit address extension registers SRO,...,SR2,

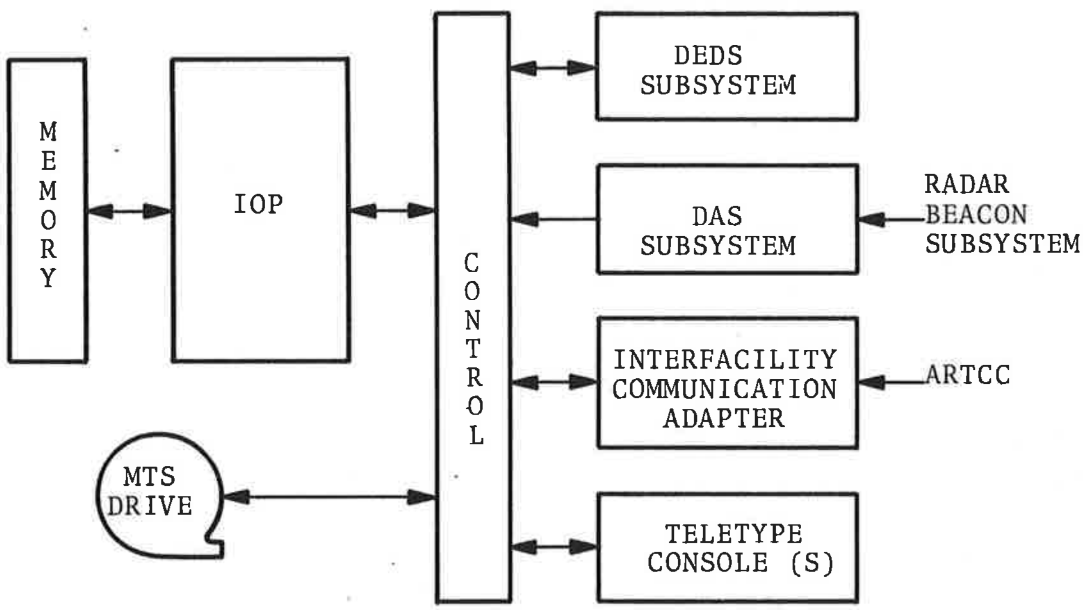


Figure 2-3. Single Beacon ARTS III Configuration

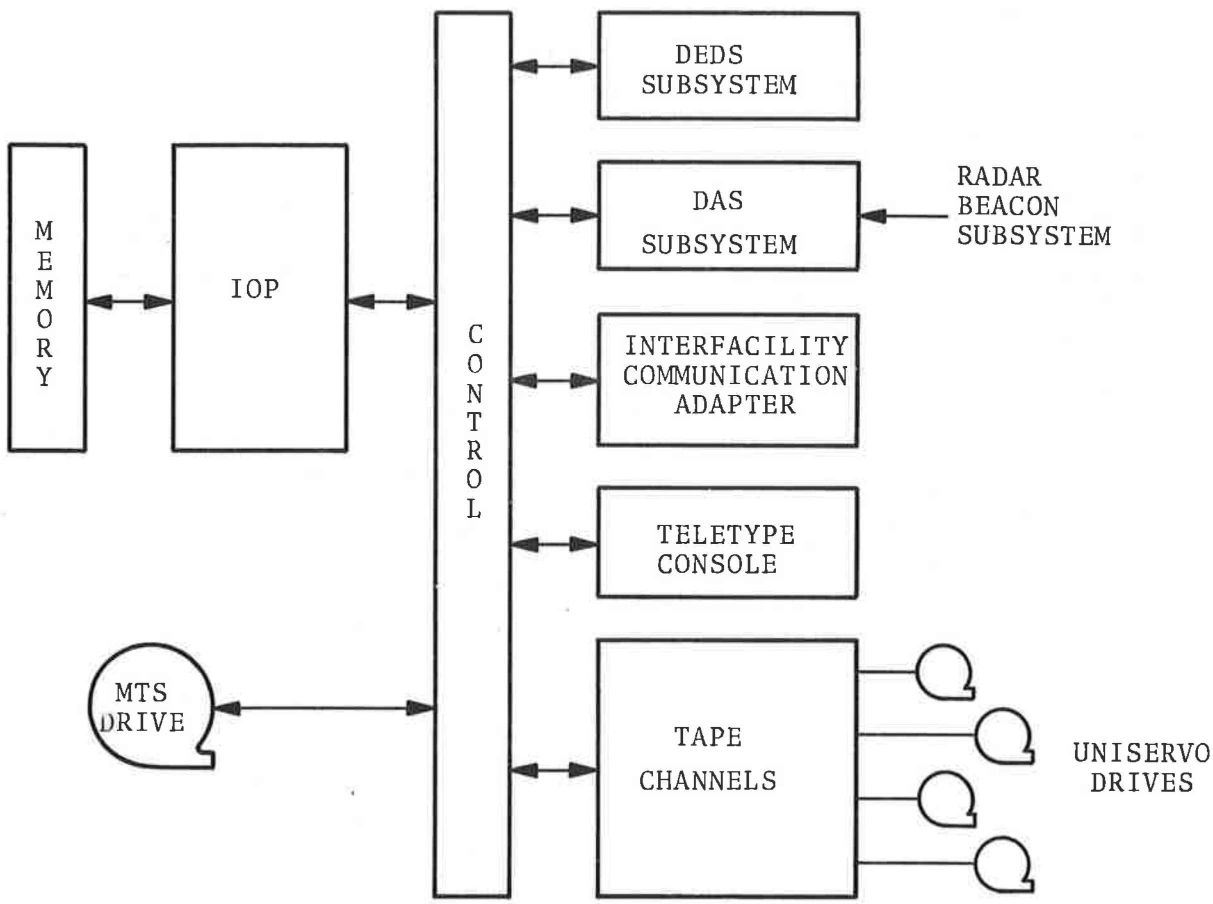


Figure 2-4. Single Beacon ARTS III Program Generation Configuration

- An 18-bit program counter-P containing the address of the next sequential instruction,
- Three 2-position control panel jump keys and four 3-position control panel stop/jump keys to alter program flow externally,
- Control panel capabilities for display of registers and of memory content, and for change of register and memory values, and
- Processor-interrupt capabilities, including support of interval timing.

Instructions are all full word (30 bits), most of which are of a single format of six fields:

- 6-bit operation code,
- 3-bit skip option field,
- 3-bit selector/modifier field,
- 3-bit index register-selection field,
- 2-bit address extension register-selection field, and
- 13-bit address field.

Operand formation is somewhat complicated and commonly involves:

- the address field,
- a selected index register, and
- a selected address extension register.

The contents of the selected address-extension register are simply attached to the left-hand side of the address-field position of the instruction itself. The contents of the selected index register are added to this 18-bit result.

It is possible to select the program counter (P- register) instead of one of three address-extension registers to extend the address. The high-order five bits of P are then attached to the left-hand side of the address field.

Instruction-operand formation supports access to one-quarter million words of memory. However, the actual use of an operand, whether as an address or as data, is governed by the selector/ modifier field, which allows eight different uses of the operand; e.g.,

- o as literal numeric data,
- o as a full-word address, and
- o as a half-word address pointing to either the upper- or lower-half-word.

The skip-option field determines conditions under which the next sequential instruction will be skipped; as examples, options exist to:

- o execute the next instruction unconditionally,
- o skip the next instruction unconditionally, and
- o skip the next instruction if the Q register is positive after execution of the current instruction.

The instructions unique to the IOP perform I/O functions or are directly related to I/O functions. The basic I/O instruction is Initiate Buffer/Initiate Chain (Op Code - 62). The effect of the instruction is to activate a channel using the I/O <u>command</u> at an indicated address. Option bits specify whether input or output is intended, and whether the I/O is to be chained. For chained I/O, the <u>address</u> of the I/O command is placed into I/O Control Memory for the channel. For non-chained I/O, the command itself is placed into an appropriate buffer address.

The I/O <u>commands</u> (addressed by the Initiate instruction) are:

- o Buffer Control Word (BCW), commanding transfer of a number of words to or from an area starting at a particular core address,

- o External Function Word (EFW), commanding a definite action on the external device (e.g., end-file, rewind), and

- o IOSTOP, terminating a sequence of chained I/O commands.

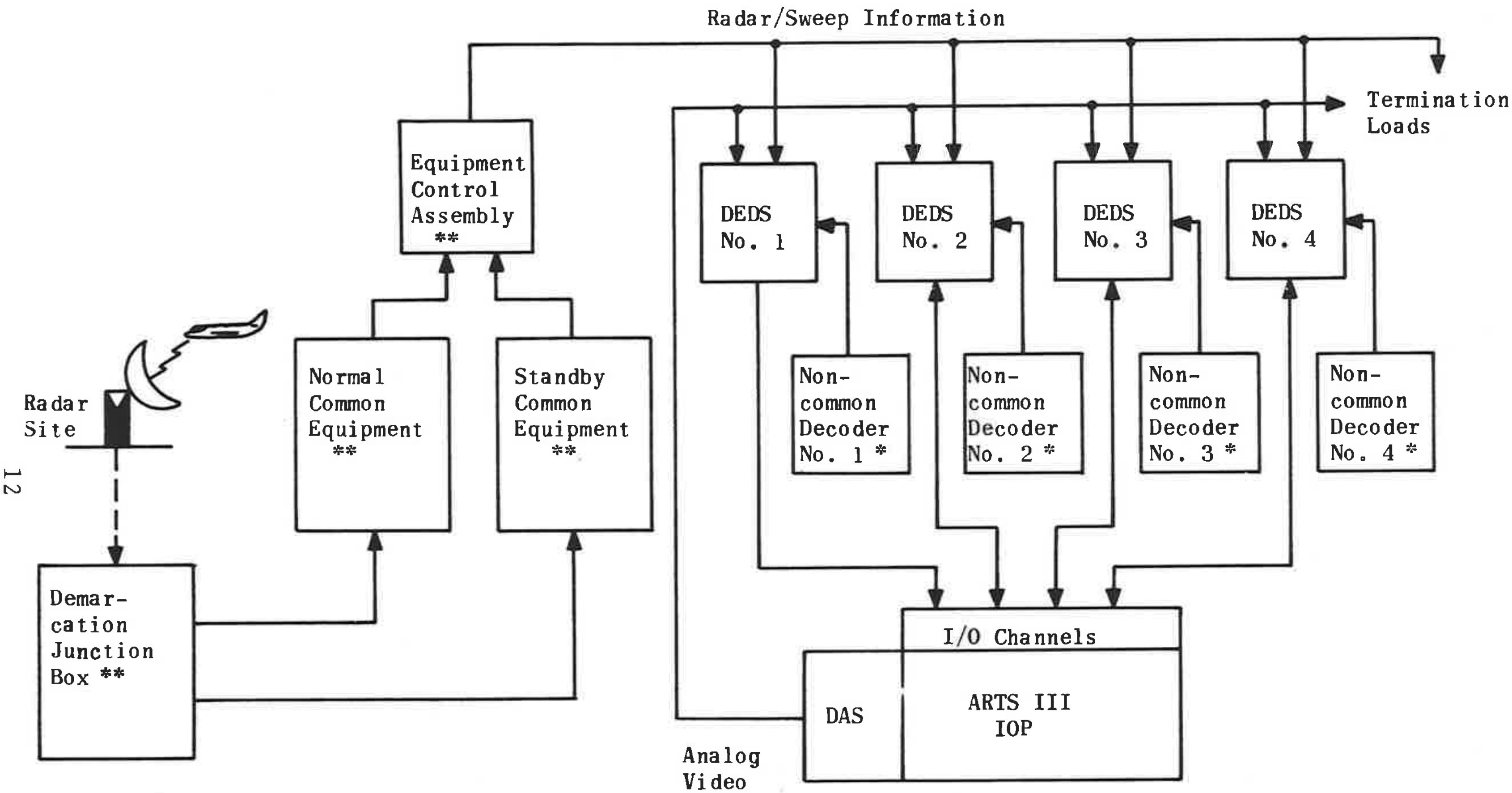
A full range of interrupt control instructions exists for both channel interrupts, and they interrupt on time-interval completion, the latter is essential for statistical sampling.

A return jump instruction is available and suitable for subroutine linkage. If the return jump is taken (the jump may be conditional on a hardware stop/jump key-setting), the current Program counter (P-register) value is placed in the jump address, and the jump is taken to the jump address plus one.

2.4 DATA ENTRY-AND-DISPLAY SUBSYSTEM

A typical single-beacon display subsystem using four DEDS consoles is shown in figure 2-5. Functionally it provides a 22-inch diameter composite presentation of broadband radar/beacon PPI video and A/N data. A time-sharing technique permits the generation of A/N data during radar dead time. A single display can present 24 Full Data Blocks (FDBs), 100 Limited Data Blocks (LDBs), 50 Single Symbols (SSs), and 15 Tabular (TAB) lines at a flicker-free refresh rate in either radar or display coordinates. A typical console display presentation is shown in figure 2-6. All displayed A/N data are sent from the DPS over a 30-bit output channel.

The data-entry devices in the console shelf permit the controller manually to request display of A/N data. Readback from the DPS permits these controller-composed request messages to be displayed in a preview area before processing by the DPS. Five quick-look selector pushbuttons allow the controller to select and display A/N data pertaining to aircraft that are controlled by another console position. The trackball is used to enter position-coordinate data into the DPS in conjunction with a composed keyboard message. Normally, these positional data are entered in conjunction with a keyboard message. It can specify the position of a track, a sensor video, or an A/N data item. As many as three data entry sets can be operational at each display. In addition to data from the data-entry sets, the display also sends console information to the DPS containing range/off-centering information. All data sent from the displays are encoded with parity, which is checked in the IOP to insure validity.



* Government-furnished Equipment (GFE)

** GFE Modified for ARTS III

Figure 2-5. DEDS Block Diagram

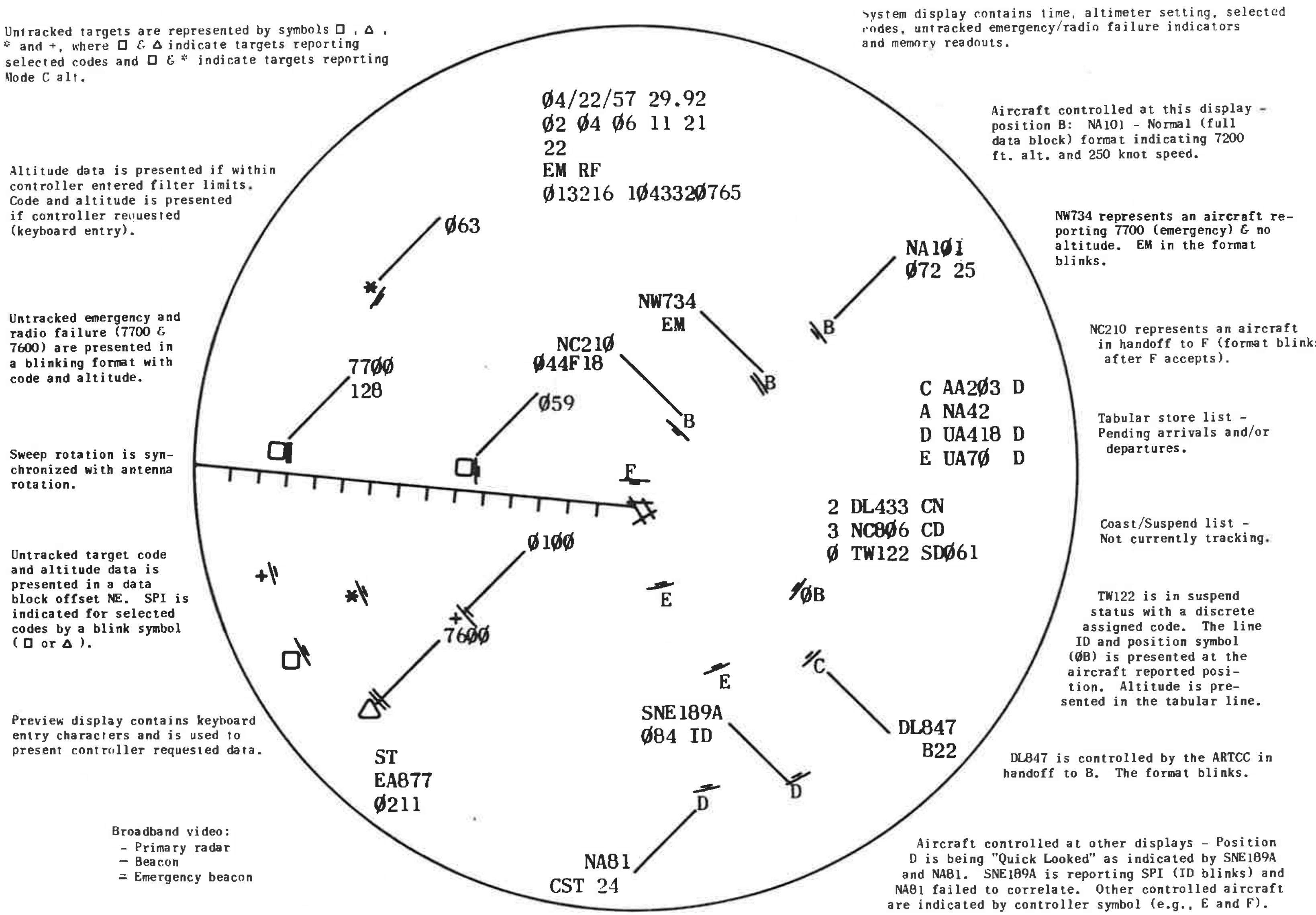


Figure 2-6. Typical DEDS Display Pictorial Diagram

3. ARTS III OPERATIONAL PROGRAM

3.1 PROGRAM FUNCTIONAL DESCRIPTIONS[5]

The software design features for ARTS III are based on a common processor program which is utilized for all single-beacon level sites. The parameters involved in a site adaptation of the program relate to three major areas:

a. Data acquisition, which can be modified for radar Pulse Repetition Frequency (PRF), mode of transponder replies, hits and/or sweeps to declare targets, and target-quality values,

b. Tracking, which can be modified for automatic target acquisition-and-termination areas, number of correlations required for acquisition, and target-quality values, and

c. Display, which can be modified for keyboard associations, character size and spacing, symbol assignment, and location of tabular data.

The operational program is divided into the various program modules shown in figure 3-1. The Executive Control Module exercises major control of the program. Functional descriptions of the program modules are given below.

3.2 EXECUTIVE CONTROL MODULE

The Executive Control Module consists of a preset function, a power-failure restart function, and a scheduling function.

3.2.1 Preset Function

The preset function initializes tables and flags, and establishes initial I/O communications with various peripheral devices. Preset is located in a buffer area and is overwritten during execution of the Operational Program (OP).

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[5]UNIVAC PX6213, Section 3. Operational Prgoram In: General System Manual

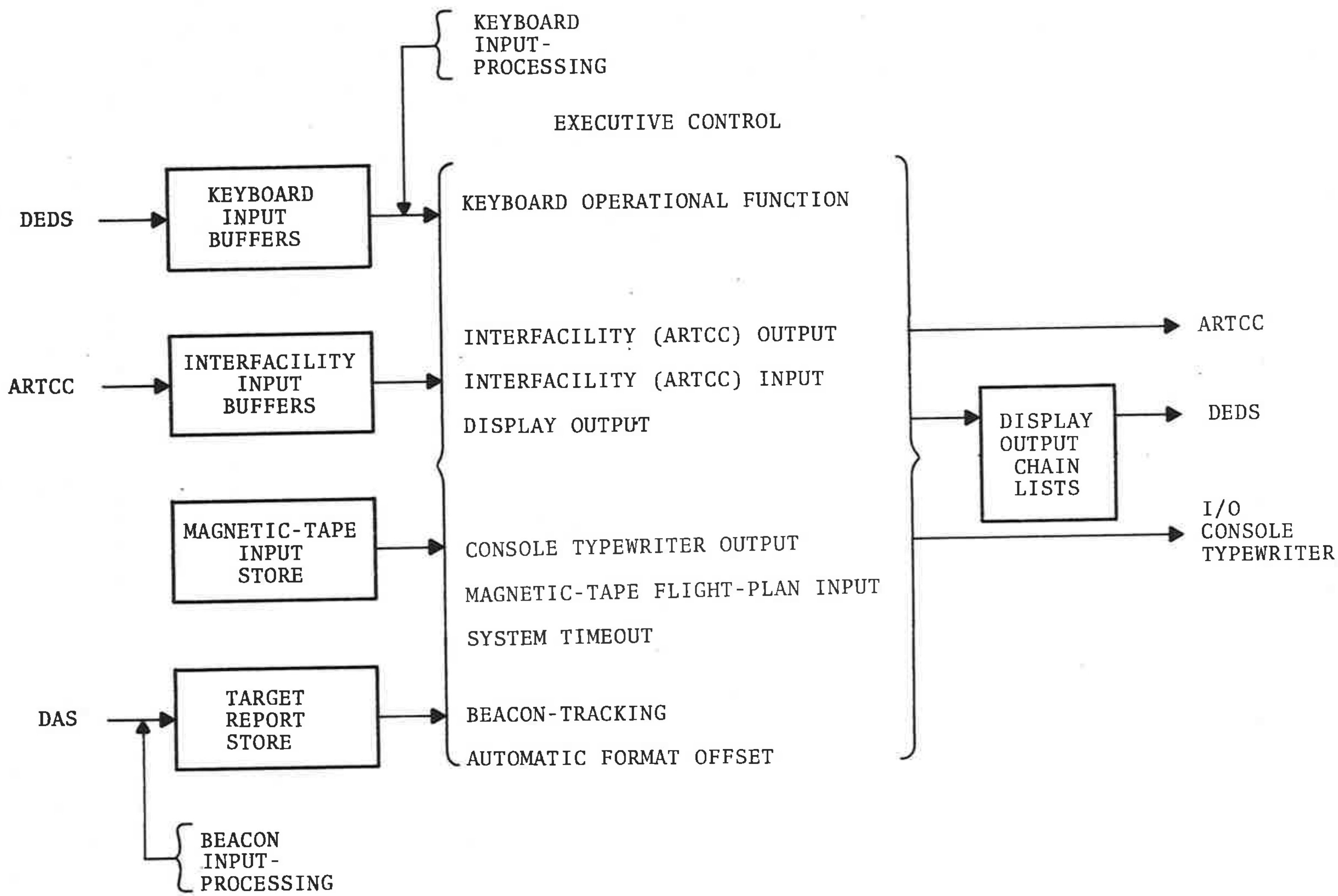


Figure 3-1. ARTS III Operational Program Modules

3.2.2 Power-Failure Restart Function

The power failure restart function is performed by two interrupt routines to prevent loss of certain memory registers during a power failure. A power tolerance interrupt occurs when power is marginal. This routine terminates all I/O activity and saves Control Memory and A,Q,P, and status registers. If power is restored before a power failure occurs, I/O activity is reestablished, and control is returned to the point of interrupt. If a power failure occurs, control is transferred to a power restart interrupt upon restoration of power, in which the aforementioned registers are restored, channel interrupt lockouts are reset to their original status, and the Real-Time Clock (RTC) is enabled. I/O chains and buffers are reinitialized via timeout and automatic restart procedures built into the various program modules.

3.2.3 Scheduling Function

The scheduling function consists of continuously monitoring the program time-to-execute flags and executing those programs whose flags indicate less time than that of the Real-Time Clock (RTC). The Executive Control Module time flags (see figure 3-2) are examined in order of priority (see table 3-1), beginning with that of the highest priority program. Just before executing a program, the program's time flag is set to the RTC plus the program's Executive time flag increment (EXINM table). After executing a program, the Executive again starts examining Executive time flags beginning with that of the highest priority subprogram (cyclic snapback).

The demand program modules (see table 3-1) are executed asynchronously. Each demand program module has its own interrupt routine preforming an associated preprocessing function, which is also used to set the respective module time-to-execute flag based on criteria contained therein.

TABLE 3-1. EXECUTIVE-CONTROLLED PROGRAMS

Program Module	Program Label	Priority	Control
Keyboard Operational Functions	KOFK	1	Interrupt
Interfacility Input-processing	ERINC	2	Interrupt
Beacon Tracking	TRACKB	3	Interrupt *
Display Output Chain Preparation	CPSE	4	1/sec/display
Console Typewriter Output	CTYPX	5	1/sec
Interfacility Output-Processing	ENROTC	6	1/sec
Magnetic-Tape Flight-Plan Input	MTFPY	7	5/min
System Timeout-Processing	STOPE	8	2/sec
Automatic Offset	AOFSTL	9	10/min/display

*NOTE: The Beacon Input Processing Task shall be performed in the interrupt state. It shall "call" the Beacon Tracking subprogram via the Executive approximately once every 125 ms for each beacon subsystem.

Subprogram Priority			
1			
2	Time when subprogram should be referenced	Time increment if referenced on a cyclic basis or set to maximum time (7 days)	Address of subprogram
.			
.			
.			
9			

Figure 3-2. Program Referencing Tables

3.3 BEACON INPUT-PROCESSING MODULE

The Beacon Input-Processing Module is executed upon receipt of each DAS interrupt (once per beacon sweep or approximately once every 2.5 ms depending on the beacon PRF). The DAS interrupt is followed by input data one word containing azimuth data and one word for each target reply. Processing of the data is performed in the interrupt state. Beacon input-processing consists of three tasks: input control, target detection, and target declaration.

3.4 BEACON-TRACKING MODULE

The Beacon Tracking Module maintains the correct association between beacon-target reports and the A/N tags identifying those targets. This is accomplished by scan-to-scan correlation. Other functions performed by the Beacon Tracking Module include automatic track acquisition, automatic track termination, automatic code assignment, and the preparation of untracked target data for subsequent display presentation.

A Tracking-Control subprogram is required to maintain a priority of processing for the various tracking functions. The priority scheme is based on the position of the radar antenna as determined by the Beacon Input Processing subprogram(s). Entry to the Tracking-Control subprogram is effected once every sector for each beacon subsystem. The Tracking-Control subprogram determines the beacon subsystem in which the tracking functions require execution (dual systems only), and then references the following tracking subroutines:

a. Primary Correlation,

b. Initial Correlation,

c. Turning Correlation,

d. Process Unused Beacon (PUB), Targets and

e. Prediction

3.5 KEYBOARD INPUT-PROCESSING MODULE

Keyboard data are received by the ARTS III Operational Program via a separate input channel for each DEDS device. The data are transferred 30 times per second per display after every refresh cycle. Input from each display consists of four words. The first word contains the display range and off-centering information. The following three words contain the keyboard's quick-look selection, character/function key depression, and trackball position change, respectively.

Four-word buffers in memory are filled via the DEDS input chain after which an interrupt is generated, and control is transferred to the KIPZ demand program module. This routine detects changes in the display/keyboard status, updates the display preview area, and adjusts the appropriate tables. The preprocessor also recognizes control character entries; i.e., Disconnect, Idle, Clear, Backspace, Space (used to separate message fields), Enter, and Trackball Enter (Slew). Keyboard Enter or Trackball Enter sets the KOF flag for subsequent execution of the Keyboard Operational Function Module by the Executive Control Module.

3.6 KEYBOARD OPERATIONAL FUNCTION MODULE

The keyboard input capability is the primary controller/system interface. Manually composed keyboard messages are used to initiate and terminate tracks to modify track data or track controller, to initiate and accept aircraft handoffs, to request and delete display of untracked target data, to reposition display of A/N information, to enter such data as time and altimeter setting, and to request the display or printout of system data. Keyboard messages also control certain operational functions including ARTCC input, magnetic-tape input, automatic offset, and selection of system configuration.

The KOFK Module processes the completed preview messages by first determining the task to be accomplished and then executing the appropriate functional processing routines. The input characters are cleared, and readback data are displayed in the preview area if required.

3.7 INTERFACILITY INPUT/OUTPUT PROCESSING MODULES

The Interfacility Program processes all data received from the ARTCC and packs and sends necessary messages to the ARTCC. Data characters are encoded in the Extended Binary Coded Decimal Interchange Code (EBCDIC). Each message consists of several fields separated by EBCDIC space characters, except for the Longitudinal Redundancy Check (LRC) field. Each field consists of an 8-bit EBCDIC character byte.

Data from the ARTCC enter the IOP via two alternate 55-word buffers, comprising one message per buffer. Data going to the ARTCC are packed in either a 55-word buffer or in one of the three 16-word acknowledge buffers. All track initiate (TI), track accept (TA), and track update (TU) messages are sent via the 55-word buffers. The other output message types use one of the acknowledge buffers. Within the computer, messages are stored two bytes per word in successive words; i.e., the first byte in bits 17-22 and the second in bits Ø-7 of the same word. A console keyboard entry is available to inhibit or resume interfacility communication, except for test messages.

Seven different message types are used in interfacility communication between the ARTCC and the ARTS III. Messages sent from the ARTCC to the ARTS III are:

a. Flight Plan (FP),

b. Flight Plan Amendment (AM), and

c. Cancellation (CX).

Messages sent both ways are:

1) Track Initiate (TI),

2) Track Update (TU), and

3) Track Accept (TA)

The seventh message type (departure message (DM)) is sent by the ARTS III to the ARTCC only. Of the seven, all but one (TU) must be answered by one of three acknowledge messages, depending on the condition of the message at the receiving facility.

a) No error detected (DA),

b) Error detected, retransmit (DR), and

c) Error detected, do not retransmit (DX).

If a message transfer between the ARTS III and the ARTCC does not occur at least once every 60 seconds, ARTS III checks the operational status of the communication link by sending ARTCC a test message (TR). ARTCC must respond with a properly received test response (DT). If not, the alarm printout IF test FAIL is requested by the ARTS III.

The Interfacility Program consists of three modules: the Enroute Input Processor (ENRIN), the Enroute Output Processor (ENROUT), and the Enroute Interrupt Routine (ENCHIN).

3.7.1 Enroute Input Processor

ENRIN processes all incoming data. Upon receipt of an End of Message (EOM) character in an input message, the Interfacility Communication Adapter (ICA) interrupts the IOP. ENCHIN sets ENRIN's Executive time flag and establishes input into one of the two alternate buffers. ENRIN processes the message and packs any necessary acknowledge message in an acknowledge buffer. If the alternate buffer is ready to process when ERIN finishes with the first, ENRIN established input into the buffer it just processed and sets its own Executive flag. This causes the Executive Control Module to access ENRIN as soon as possible to process the alternate buffer. All format errors encountered after this point are acknowledged by a DX unless otherwise specified. DX, DA, and DR messages are never acknowledged even if erroneous.

3.7.2 Enroute Output Processor

ENROUT packs and sends all necessary messages to the ARTCC. Unlike ENRIN, ENROUT is accessed periodically by the Executive Control Module. If the interfacility output channel is active, ENROUT will exit. Otherwise, it will scan the Central Store (CTS) table for any TI, TA, or TU messages to send. Only one message is packed and sent per access. If a TI or TA message is sent while a TU chain is being packed, ENROUT saves the index of the TI or TA message for use as a Start Search Index on the next access. In this case, ENROUT sets a flag for ENCHIN to set its Executive flag when activity on the input channel stops.

3.7.3 Enroute Interrupt Routine

ENCHIN processes all interrupts on the interfacility channel as follows:

a. External Interrupt Line Parity Error,

b. Input Data Line Parity Error,

c. Input Lateral Parity Error,

d. LRC Parity Error,

e. Input Timing Error,

f. Input Monitor Interrupt,

g. EOM Interrupt,

h. Output Lateral Parity Error,

i. Output Timing Error, and

j. Output Monitor Interrupts.

3.8 AUTOMATIC FORMAT OFFSET MODULE

The Automatic Format Offset Module eliminates as much overlapping as possible of A/N data on actively controlled track formats. The active track formats are periodically monitored for overlap. If overlap exists, the offset of one of the formats is changed. Any active track format is not offset if it overlaps another type of format; i.e., untracked aircraft, handoff tracks, preview data, or single symbols. Offsetting is such that no formats will be moved outside of the display perimeter. If overlap is found at all offsets, no offset change will be made.

3.9 CONSOLE TYPEWRITER OUTPUT-PROCESSING MODULE

The Operational Program provides two types of printouts:

a. Alarm printouts, those requested by various program modules as a result of program-detected hardware malfunctions. The printouts provide an indication of system performance. Decisions regarding the impact of any malfunction; i.e., system usability, are left to the operator.

b. Recording printouts, those requested by the Keyboard Input (KIP), Processing Module upon receipt of selected (supervisory) messages.

3.10 SYSTEM TIMEOUT-PROCESSING MODULE

The System Timeout-Processing Module performs a variety of unrelated tasks in support of the overall system. These tasks may be regarded as part of the Executive Control Module responsibility but are performed within a program to provide low priority at the desired execution frequencies. Following is a list of performed tasks:

a. Monitor display input activity on all dispaly channels,

b. Monitor the DAS input activity,

c. Monitor the RTC, prevent overflow, and update the dispaly readout,

d. Update the memory contents readout,

e. Time out the EM/RF indicators,

f. Scan the track files, clearing those which have been in delayed terminate status for one second, this ensures that the output chains have been properly updated before the file is reused,

4. EXAMINATION OF PERFORMANCE-MEASUREMENT MONITORS

Examination of current performance-measurement monitors entailed investigating available literature on software, hardware, and hybrid monitors.

A software monitor is a computer program which obtains control of the computer periodically, to observe what it can about the current machine state, and to record this status generally onto magnetic tape for subsequent processing by a separate program, and then returns control to the operational program.

A hardware monitor is an electronic device containing counters, timers, and probes. The probes are attached directly into the circuitry of the object computer. Probes triggered by impulses in the object computer activate counters and timers in the monitor. Usually, the counters and timers are periodically read out onto magnetic tape for later analysis by a computer program.

A hybrid monitor is under control of an on-line auxilliary computer which uses both hardware- and software-measurement tools. Probes to the object computer serve the same function as a hardware monitor but may also be used to trigger interrupts in the object computer. The technology for these monitors is still largely in the development stage.

4.1 SOFTWARE MONITORS

The software monitors surveyed include:

CPS II	Applied Computer Technology, Inc.,
PPE	Boole and Babbage, Inc.,
CUE	Boole and Babbage, Inc.,
PROGLOOK	COSMIC,
SUPERMON	COSMIC,
AMAP	IBM,
LEAP	Lambda Corporation, and
System/LEAP	Lambda Corporation.

In general, software monitors employ two distinct types of measurement techniques; event-driven and sampling.

An event-driven monitor receives control on the occurrence of selected events within a computer system. An example of a software mechanism used in the event-dirven technique is that of instruction overlays, which are strategically implanted at various points throughout the software (both in the executive routine and the program modules) and are overlayed for a measurement run during system initialization.

The sampling monitor involves interrupting the operational program periodically, generally by means of a hardware-interrupt mechanism. On occurrence of the interrupt, control is given to the monitor, which in turn records the state of the system, indicates to the computer the next time at which it wants to obtain control, and returns control to the operational program.

The prime advantage of software monitors is that they can correlate the observed data. They can provide comprehensive cause-and-effect analysis of system performance. They can obtain quantitative variables which are concerned with the magnitude of some quantity, and descriptive variables which identify the respective system element. The level of data and the amount of data can be varied to meet the measurement needs of the system. The disadvantages of software monitors are that they incur system burden during measurement runs in terms of core memory, generally the utilization of a magnetic-tape unit, and additional CPU execution time. This additional execution time in turn, distorts the system; however, typically the overhead time incurred is from one to five percent depending on the measurement techniques and their frequencies of usage.

Another disadvantage for a sampler monitor, particularly if it is asynchronous, is that it requires a hardware interrupt usually generated from a timer to operate.

4.2 HARDWARE MONITORS

The hardware monitors surveyed include:

CMP II	Applied Computer Technology, Inc.
X-RAY	Computer Learning and Systems Corp.,
SUM	Computer Synectics, Inc.,
DYNAPROBE/DYNAPAR	COSMIC, and
SMIS	IBM.

Hardware monitors are electronic devices, and use the event-driven measurement technique. Usually, they comprise a collection of counters, timers, and electronic probes. The probes or sensors are attached to specific signal wires to measure the presence, duration, or absence of electrical impulses. The signals are typically routed into a programmable plugboard, in which wired logic can be used to enter data into coutners and timers. Generally, available logical operations are "and," "or," and "complement," and can produce data on combinations of functions such as I/O-CPU overlap. Counters are used to indicate a one-to-one relationship between counts and events. Timers are used to indicate duration of events. Most of the monitors have a real-time clock, (RTC), and its readings make possible correlation of observed events with other factors, such as the program modules that the computer was executing. Such data are summarized, and are usually written onto magnetic tape for future data reduction.

The advantages of hardware monitors are that they do not affect, or degrade, the operation of the system being measured. They can monitor some details of the activity of peripheral equipment that are not reflected in the CPU, and they do not incur any system burden since they do not use resources of the host computer. The hardware monitor is machine and operating-system software-independent and can be utilized in a variety of computing systems.

Their disadvantages include an inability to obtain software tables, queues, pointers, and module names; thus, they are unable accurately to relate hardware utilization to the software in operation at that time. They require knowledge of the hardware monitor's programmable plugboard and a working knowledge of the electronics of the system under study. The user must relate what he wants to measure to specific hardware functions of the computer, and determine how to measure these functions, where to attach the probes, and how to interconnect the logic circuitry of the plugboard.

4.3 HYBRID MONITORS

One hybrid monitor, SNUPER (University of California), was surveyed. The SNUPER computer is a modified XDS Sigma-7. The monitor is attached via probes to the object computer at a number of points. The software program in the SNUPER computer selects subsets of these points and collects statistics on them.

The hybrid concept is primarily in the experimental or development stages and attempts to combine the best features of both hardware and software monitors in a single device. Nevertheless in combining these features, it also incurs, on the part of the user, the complexities and detailed knowledge associated with both the hardware and software monitors.

4.4 SELECTION OF PROTOTYPE MEASUREMENT TOOLS

After studying the Single-Beacon ARTS III System and examining Performance Measurement Monitors, appropriate prototype measurement tools were selected. Criteria used in their selection included measurement techniques, evaluation of advantages and disadvantages of the various monitor types, ARTS III impact, ARTS III utilization needs, and costs.

Hybrid monitors did not receive serious consideration because of the experimental phase of their development, their complexities, the user's knowledge requirements, costs, and also the simplicity of software design of the Single Beacon ARTS III Operational Program.

Hardware monitors, on the other hand, received serious consideration. However, at this stage in the development of ARTS per formance-measurement tools, it became evident that their disadvantages outweighed their advantages. Major factors included knowledge of the electronics of the ARTS III IOP computer, knowledge with respect to the logic circuitry of the plugboard, the necessity of debugging hardware-monitor probe connections (in some instances with software resident with a version of the ARTS III Operational Program), and the receipt of approval physically to connect a hardware monitor to an ARTS IOP at the test-bed facility in Minneapolis, MN. Other factors included additional ARTS utilization needs plus the cost of a hardware monitor itself. Because of the aforementioned factors, it was decided not to select a hardware monitor.

Software monitors in turn, as previously discussed, have their disadvantages; however, relatively, software monitors offered the most promising means to meet the immediate needs for prototype performance-measurement tools.

Two software measurement tools were selected for prototype development; an Executive Scheduler Tracing Monitor using the event-driven measurement technique, and a Sampler Monitor using the sampling-measurement technique. These prototype measurement tools are discussed in detail in Section 5.

5. PROTOTYPE MEASUREMENT TOOLS

Two prototype software-measurement tools were developed and tested at the ARTS III Test-Bed Facility in Minneapolis MN; i.e., the Executive Scheduler-Tracing Monitor and the Sampler Monitor. These tools were integrated into the Operational Program of the ARTS III Single-Beacon Tracking Level System (version OP-05, dated 6 January 1972) and measurements were obtained from their use (see Section 6).

In the development of these software tools, existing logic and coding resident in the ARTS III operational Program were used wherever feasible. Specifically, the Executive Scheduler Tracing Monitor was overlayed in the TIMER Module,[6] employing the module's operating techniques, such as bit settings and JUMP KEY to initiate the measurement run and to begin the measurement function respectively. Also, the DAS and KIPZ measurements are obtained by the TIMER Module, and for both measurement tools, the VI-C Interrupt Module and some of the coding of the Data Extractor Module are used.

5.1 EXECUTIVE SCHEDULER-TRACING MONITOR

The Executive Scheduler Tracing Monitor uses the event-driven technique via instruction overlays to capture the following measurements:

a. Duration of execution time of each major program module each time it is executed, together with time stamp and module identification,

b. DAS and KIPZ Demand Program Module information, consisting of number of times these modules were executed and their cumulative execution times,

[6] Reference UNIVAC PX 66213, Section 3, Utility Routines, Appendix A, Operating Procedures, In: General System Manual

c. Number of targets being processed,
d. Contents of Status register,
e. Magnetic-tape status word, and
f. EXAOM table, containing the next iteration of execution times for the respective program modules.

During system initialization, information is given to the Preset function of the Executive Control Module regarding the collection of measurement data for the specific run. If measurement data have been requested, the Preset function overlays two instructions in the Executive Control Module. One instruction overlay pertains to an aspect of the monitor's data-collection function which is discussed later. The other instruction overlay relates to data-capturing, and is superimposed at that memory location in the Executive Control Module where control is transferred to the appropriate program module for execution. Execution of this instruction overlay transfers control to the Executive Scheduler Tracing Monitor.

5.1.1 Functional Flow

Figure 5-1 depicts the functional flow of the Executive Scheduler-Tracing Monitor. As shown, the measurements are stored on magnetic tape. Actually, two measurement records are stored, each from their own buffers. However, sufficient time must elapse between writing the two records on magnetic tape. It is for this reason that an instruction overlay is used. The instruction is superimposed at that location in the Executive Control Module immediately following the program module's time-to-execute parameter. Control is subsequently transferred to a routine which determines: (1) if BUFF II data are to be recorded, and if so, (2) whether sufficient time has elapsed (a program parameter) since the last output of BUFF I before writing BUFF II data on tape. Control is then returned to the Executive Control Module in accordance with the appropriate action for the aforementioned conditions.

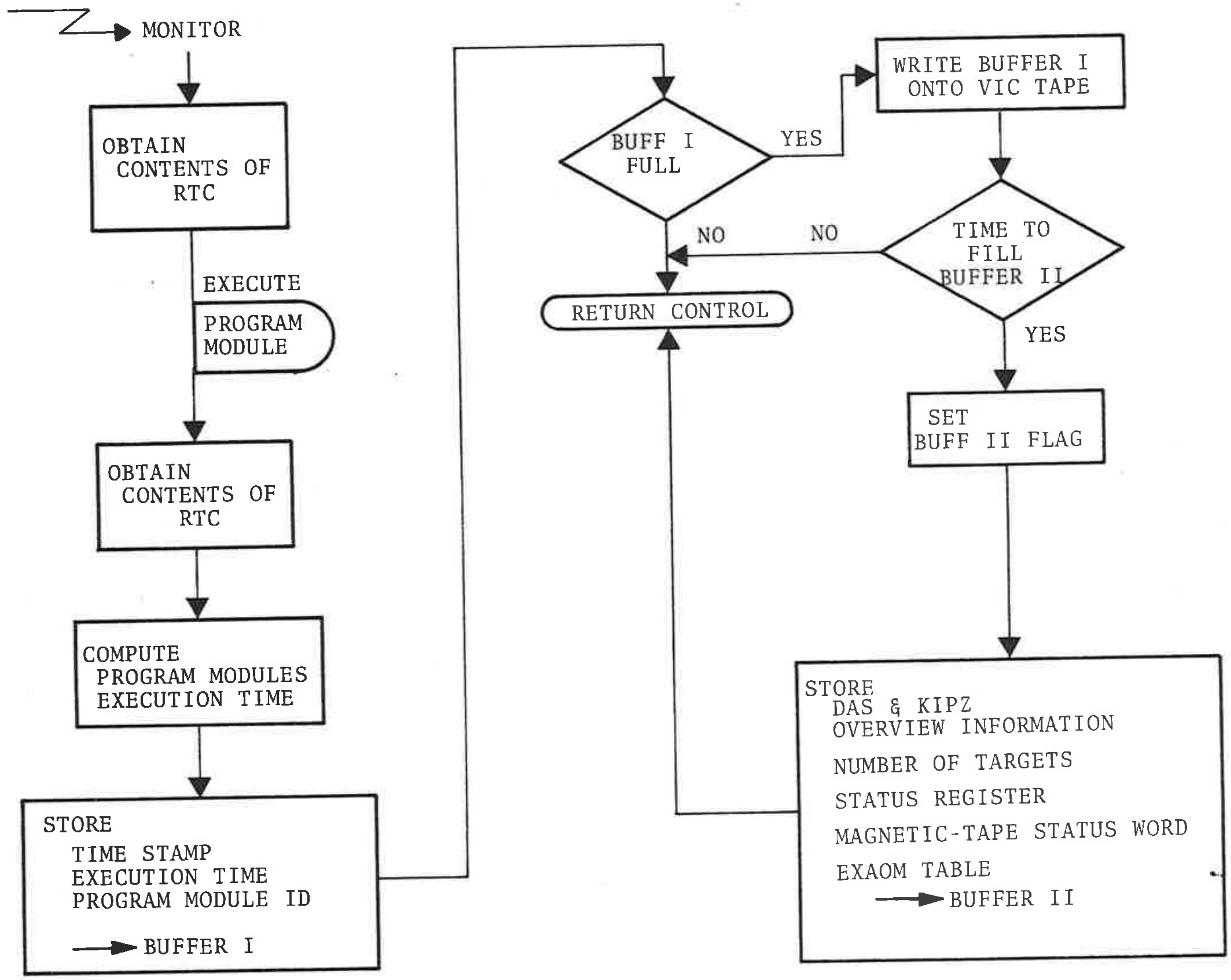


Figure 5-1. Executive Scheduler-Tracing Monitor Flow Diagram

5.2 SAMPLER MONITOR

The Sampler Monitor uses the time-driven technique via means of the IOP Monitor Clock to interrupt the basic ARTS III Operational Program and capture the following measurements:

a. Contents of P-counter when interrupt occurred,
b. Real Time Clock,
c. Status register,
d. IX-7,
e. Magnetic-tape status word,
f. DAS and KIPZ Demand Program Module information, consisting of number of times these modules were executed and their cumulative execution times,
g. Number of targets being processed,
h. I/O channel activity,
i. EXAOM table, containing the next iteration of execution times for the respective program modules, and
j. Eighteen closed subroutines calling addresses.

5.2.1 Constraints

Before discussing the Sampler Monitor, it should be noted that the basic ARTS III Operational Program requires that Beacon Input Processing be performed as the beacon replies are being received from the DAS. Beacon Input Processing entails: (1) input control, (2) target detection, (3) target declaration, and (4) sector monitoring. Thus, for each beacon interrogation period (sweep), the DAS transmits an INITIAL message interrupt via I/O channel 0 approximately 25 μs before radar zero range. The INITIAL message contains the antenna azimuth and the interrogation mode for subsequent beacon replies. REPLY messages containing corresponding beacon code and range data are received asynchronously depending on the range of the responding aircraft.

The first REPLY message may be received as early as 21.5 μs after radar zero range. Therefore, the minimum time interval between transmission of the first REPLY message is approximately 46.5 μs.

During this time interval, the program module that services the DAS interrupt must initiate an input buffer and must be prepared to receive REPLY messages, or the data could be lost and an overload condition triggered.

With regard to DPS interrupt priority, the Monitor Clock interrupt could indeed occur during this critical time interval. Therefore, care must be taken to ensure that Monitor Clock interrupt-processing in no way adversely affects the processing of beacon interrogation replies.

5.2.2 Functional Flow

Figure 5-2 depicts the functional flow of the Sampler Monitor. In consideration of the aforementioned constraints, for prototype development purposes, the Monitor Clock interrupt processing was kept to a minimum, consisting of (1) capturing the P-counter contents at the time of the interrupt, (2) setting a flag to indicate that the interrupt occurred, and (3) returning control to the interrupt routine with interrupt lockout removed. The actual data collection and data-recording were performed subsequent to the interrupt, and effectively as the lowest-priority program module.

As with the Executive Scheduler-Tracing Monitor, during system initialization, information is given to the Preset function regarding the collection of measurement data for the specific test run. If measurement data have been requested, the Preset function sets the Monitor Clock interrupt entrance location with a return jump instruction to the Sampler Monitor, sets the Monitor Clock register to the sampling time interval, and enables the Monitor Clock. The Preset function also overlays an instruction in the Executive Control Module for purposes of data collection and data-recording.

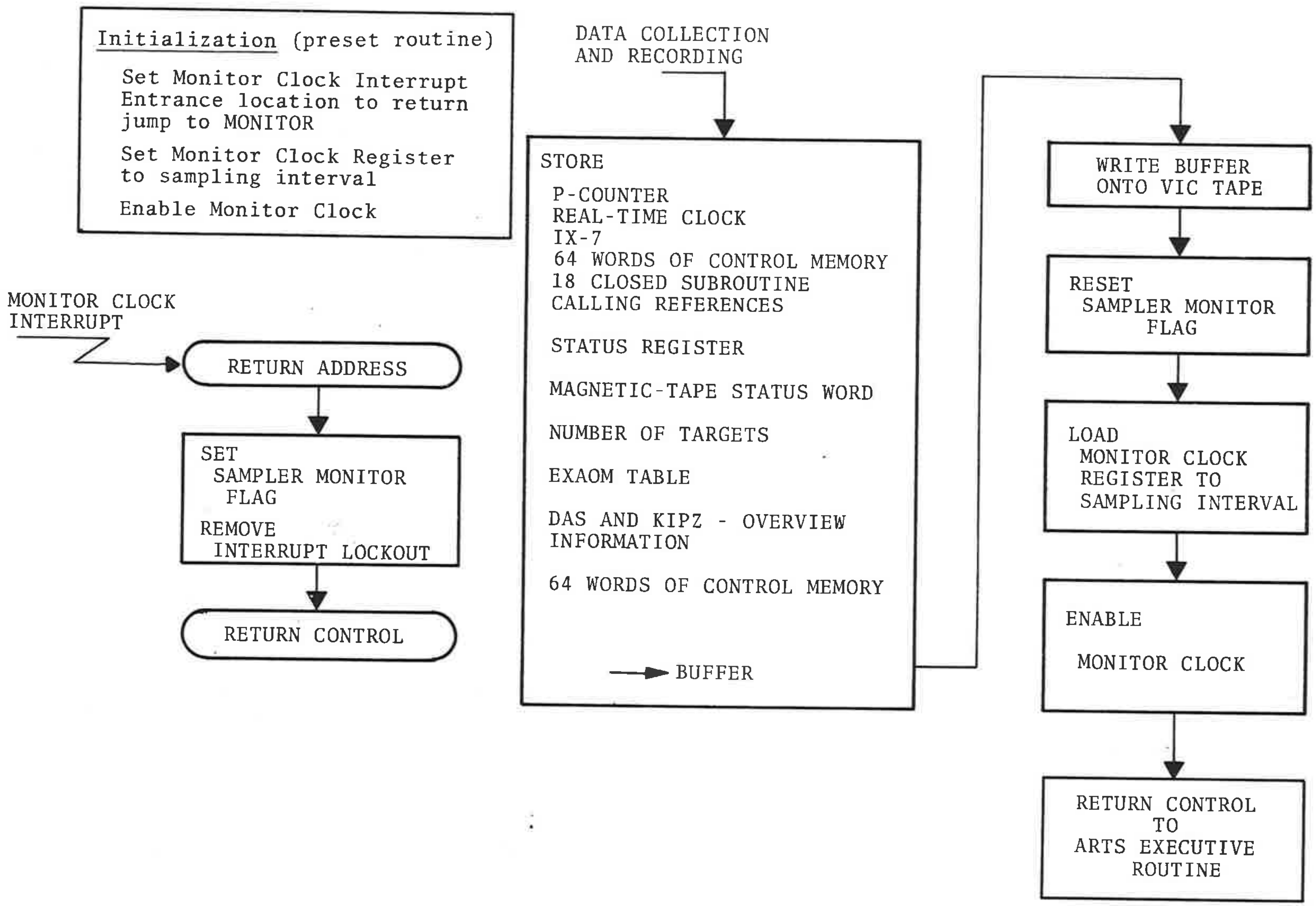


Figure 5-2. Sampler-Monitor Flow Diagram

5.2.3 Linkage-Tracing

Subroutine linkage in OP-05 is programmed by means of an RJ or LBJ instruction. For the RJ instruction, it stores the address of the next sequential instruction into the address specified by the Y field of its instruction then jumps to the address as contained in Y plus 1. The LBJ instruction stores the address of the next sequential instruction into the specified index register (for OP-05, index register 7 is always specified) and jumps to the address specified in its Y field.

Linkage measurements obtained via the Sampler Monitor included the contents of index register 7 and the entry locations of 18 closed subroutiens. After recording these entry locations, the Sampler Monitor overwrites zeros in these entry locations. Thus, the data reduction-and-analysis program can examine these data, ascertain whether the subroutine was executed since the last Sampler Monitor interrupt, and if so, obtain the memory location that last called the subroutine. Similarly, the contents of index register 7 can be examined for possible subroutine linkage.

5.2.4 I/O Channel Activity

The Sampler Monitor obtains measurements of Control Memory to determine the level of I/O channel activity.

Since I/O channel activity is gated through Control Memory, the Sampler Monitor measures the activity within a given sample (i.e., on a per-interrupt basis) by capturing the contents of Control Memory twice, initially upon entering, and again immediately before exiting, the Sampler Monitor's data-collection routine. Thus, the data reduction-and-analysis program can process these measurements by comparing the two readings within a sample, summing detected changes for a measurement run, and listing the results for the 16 channels.

6. PRELIMINARY DATA REDUCTION-AND-ANALYSIS

The measurement data obtained at the Minneapolis Test-Bed Facility were converted from a 30 to 36-bit word format for processing at TSC on PDP-10 computer. Preliminary data reduction-and-analysis programs were developed which resulted in corresponding reports for the prototype measurements tools. These reports are discussed in the following subsections.

6.1 EXECUTIVE SCHEDULER-TRACING MONITOR REPORTS

Measurement data recorded by the Executive Scheduler-tracing Monitor are of two types as follows. (1) The more-frequent with its identification consists of a time stamp, module indentification, and duration of execution time for each program module each time it is executed. (2) The other with its identification contains DAS and KIPZ information - (consisting of the number of times these modules were executed and their cumulative execution times). The record also contains the number of targets being processed, contents of the status register, magnetic-tape status word, and the contents of the EXAOM table (containing the next iteration of execution times for the respective program modules).

From the measurements obtained, two reports were generated, a Program Modules-Utilization Report and a Program Modules-Timing Distribution Report.

6.1.1 Program Modules-Utilization Reports

The table portion of this report (see figure 6-1) is indexed by the major program and demand program modules mnemonics, their corresponding cumulative execution times in seconds, and their corresponding percentage of utilization. Also contained in the report is a "pie" chart depicting the various program and demand program modules. Item 10 in the modules mnemonics column of the referenced figure, "Idle Time." references the Executive Control Module which effectively in the ARTS III System is idling waiting to do work (refer to section 3.2.3).

Figure 6-2 is the same type of graph as figure 6-1, except that there is no idle entry in the modules mnemonics column. This figure (6-2) depicts the relative percent of application module execution time.

Figure 6-1 through 6-6 comprise three sets of graphs for three corresponding measurement runs recorded on tapes 205, 445, and 510.

These measurement runs were obtained during second-shift operation and denote low aircraft activity. The measurement data for the three runs are indicative of one another with CPU busy factors of 18.43, 18.62, and 22.61 percent, respectively. Similary, the percentages of relative DAS execution time are 81.42, 82.16, and 82.18. Further analysis of the remaining application program modules times shows that the percentage of utilization is within reasonable limits.

6.1.2 Program Modules-Timing-Distribution Report*

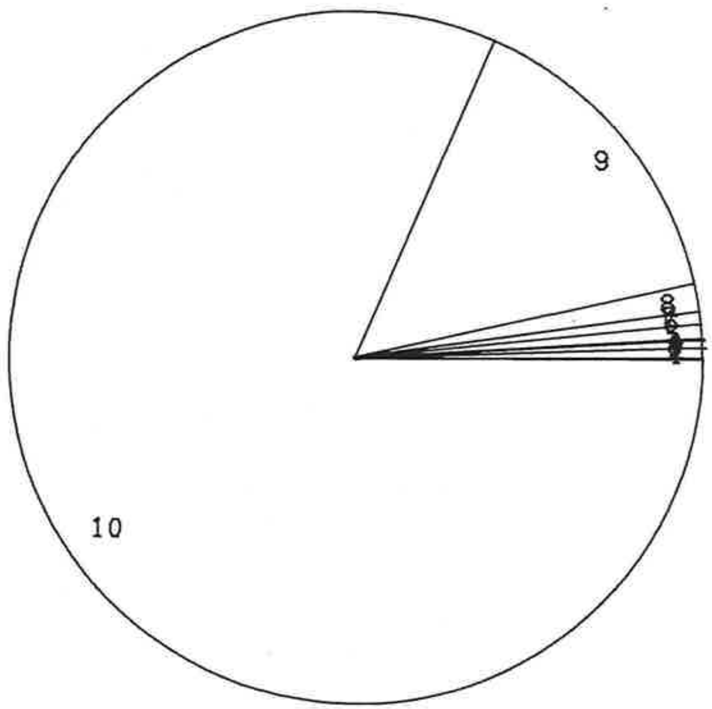
This report (see figure 6-7) is in table format indexed by the major application modules and their corresponding distribution of execution times depicted in milliseconds. Some of the entries as shown in the figure are depicted as having zero execution time. This is caused by the granularity of the real-time-clock being 1 ms. In these instances, the contents of the real-time-clock both immediately before and after the execution of the referenced program module were found to contain the same value.

Two Program Modules-Utilization Reports were generated from measurement data collected on tapes 510 and 4173. These reports are shown in figures 6-7 and 6-8.

6.2 SAMPLER MONITOR REPORTS

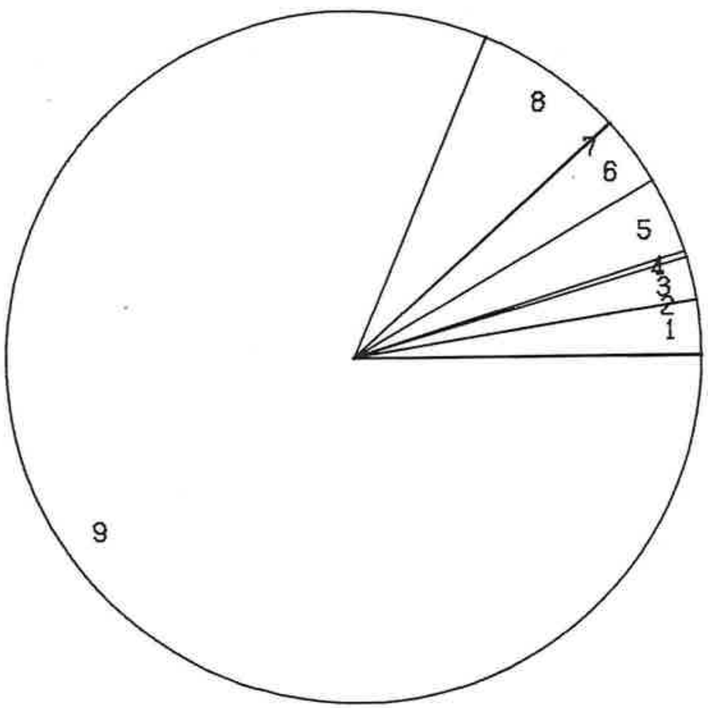
The Sampler Monitor recorded measurements consisting of

*The numbers appearing adjacent to the program modules names depict the number of times the corresponding modules were expected. The columns these numbers appear in are headed by the times of execution; i.e., 0 through 6 ms.



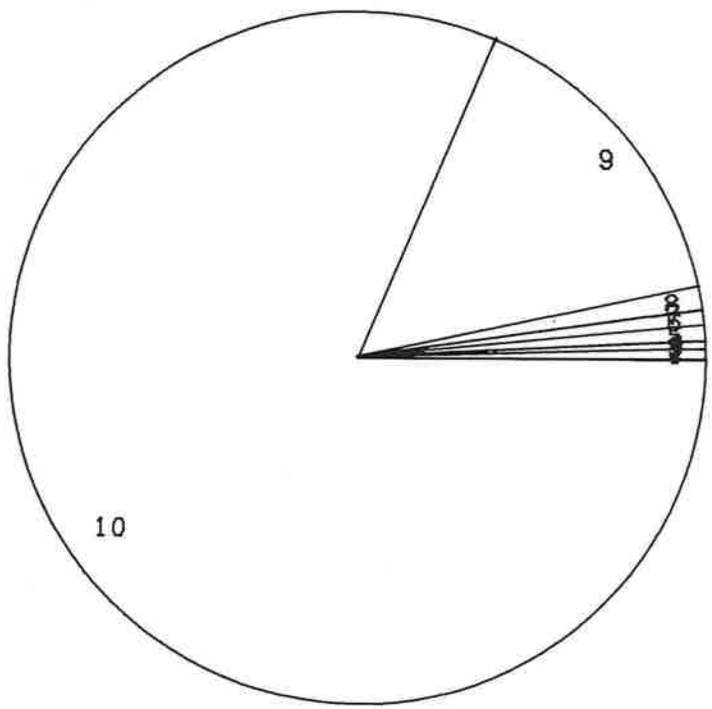
ITEM	AMOUNT	PCTG
1 AOFSTL	4.09	0.46
2 ENROTC	0.04	0.00
3 STOPE	3.27	0.36
4 CTYPX	0.49	0.05
5 CPSE	5.94	0.66
6 TRACKB	5.36	0.60
7 KOFK	0.07	0.01
8 KIPZ	11.53	1.28
9 DAS	134.96	15.00
10 IDLE TIME	733.83	81.57
	899.60	

Figure 6-1. Program Modules-Utilization Report-205 With Idle Entry



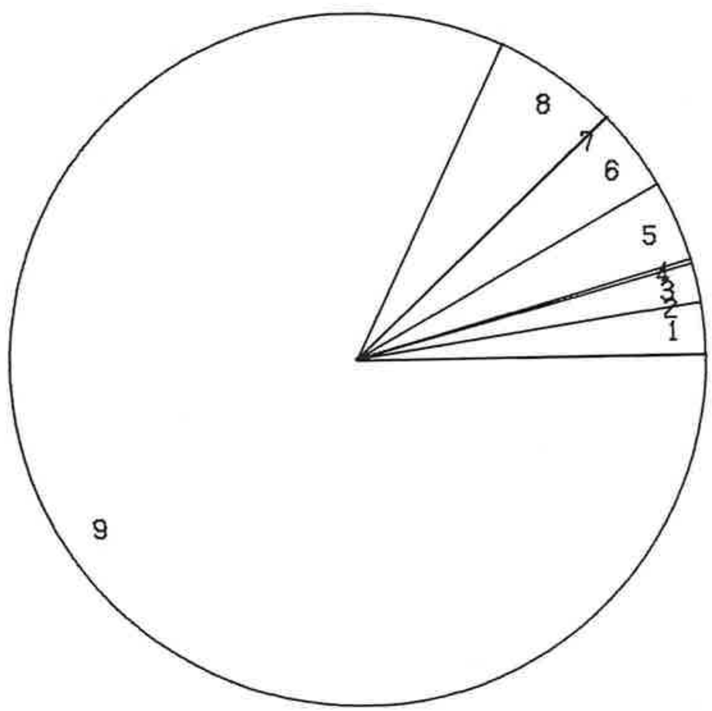
ITEM		AMOUNT	PCTG
1	AOFSTL	4.09	2.47
2	ENROTC	0.04	0.02
3	STOPE	3.27	1.98
4	CTYPX	0.49	0.29
5	CPSE	5.94	3.59
6	TRACKB	5.36	3.23
7	KOFK	0.07	0.04
8	KIPZ	11.53	6.96
9	DAS	134.96	81.42
		165.77	

Figure 6-2. Program Modules-Utilization Report-205 Without Idle Entry



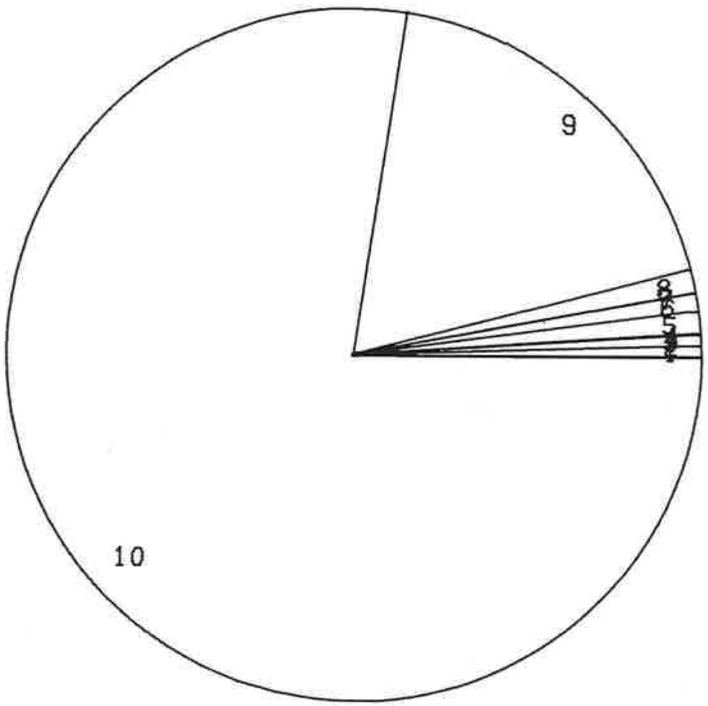
	ITEM	AMOUNT	PCTG
1	AOFSTL	6.33	0.43
2	ENROTC	0.02	0.00
3	STOPE	4.86	0.33
4	CTYPX	0.52	0.04
5	CPSE	10.28	0.71
6	TRACKB	10.38	0.71
7	KOFK	0.12	0.01
8	KIPZ	15.86	1.09
9	DAS	222.80	15.30
10	IDLE TIME	1184.92	81.38
		1456.09	

Figure 6-3. Program Modules-Utilization Report-445 With Idle Entry



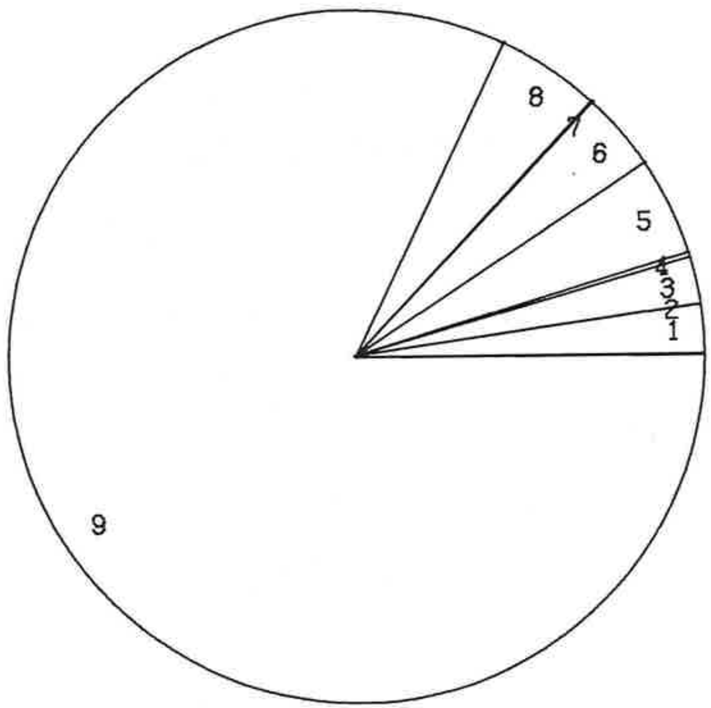
ITEM	AMOUNT	PCTG
1 AOFSTL	6.33	2.33
2 ENROTC	0.02	0.01
3 STOPE	4.86	1.79
4 CTYPX	0.52	0.19
5 CPSE	10.28	3.79
6 TRACKB	10.38	3.83
7 KOFK	0.12	0.05
8 KIPZ	15.86	5.85
9 DAS	222.80	82.16
	271.17	

Figure 6-4. Program Modules-Utilization Report-445 Without Idle Entry



ITEM	AMOUNT	PCTG
1 AOFSTL	6.19	0.50
2 ENAOTC	0.06	0.00
3 STOPE	6.05	0.49
4 CTYPX	0.70	0.06
5 CPSE	12.78	1.04
6 TRACKB	10.23	0.83
7 KOFK	0.19	0.02
8 KIPZ	13.46	1.09
9 DAS	229.11	18.58
10 IDLE TIME	954.06	77.39
	1232.83	

Figure 6-5. Program Modules-Utilization Report-510 With Idle Entry



ITEM		AMOUNT	PCTG
1	AOFSTL	6.19	2.22
2	ENROTC	0.06	0.02
3	STOPE	6.05	2.17
4	CTYPX	0.70	0.25
5	CPSE	12.78	4.58
6	TRACKB	10.23	3.67
7	KOFK	0.19	0.07
8	KIPZ	13.46	4.83
9	DAS	229.11	82.18
		278.77	

Figure 6-6. Program Modules-Utilization Report-510 Without Idle Entry

	0	1	2	3	4	5	6	
AUTOMATIC FORMAT OFFSET				6	52	2		
SYSTEM TIMEOUT PROCESSING		10	92					
INTERFACILITY OUTPUT PROCESSING	25	24	2					
CONSOLE TYPEWRITER OUTPUT	23	28						
DISPLAY OUTPUT PROCESSING	38	315	1					
BEACON TRACKING	209	132	64					

Figures 6-7. Program Modules-Timing Distribution T-510

	0	1	2	3	4	5	6	
AUTOMATIC FORMAT OFFSET				217	5			
SYSTEM TIMEOUT PROCESSING		274	103					
INTERFACILITY OUTPUT PROCESSING	189							
CONSOLE TYPEWRITER OUTPUT	161	28						
DISPLAY OUTPUT PROCESSING	778	536	1					
BEACON TRACKING	581	402	128	7				

Figure 6-8. Program Modules-Timing Distribution T-4173

P-counter, Real-time-clock, status register, IX-7, magnetic status word, DAS, and KIPZ demand module information (consisting of the number of times these modules were executed and their cumulative execution times, number of targets being processed, I/O channel activity), EXAOM table (containing the next iteration of execution times for the respective program modules), and 18 closed subroutines calling addresses.

Two Sampler Monitor Reports were implemented, a P-Counter Distribution Graph and an I/O Channels Activity Report.

It should be noted that in processing the Sampler Monitor, measurement data-timing information on itself had been provided in addition to timing information on ARTS III.

6.2.1 P-Counter Distribution Graphs

One of the measurements obtained by the Sampler Monitor was the contents of the Program Counter (P-Counter) at the time that the interrupt occurred. These data were processed by the reduction-and-analysis programs which generated a P-counter distribution graph for the respective measurement run.

The P-counter (see table 6-1) graph is indexed by the program module mnemonic, the memory ranges of the program module, the number of interrupted occurrences within this memory range, and an execution-percent distribution. A summary of the total samples monitored and the maximum number of targets tracked for the measurement run also appear in each graph.

Tapes 114, 284, 469, and 1227 were recorded at the Test-Bed Facility in Minneapolis. The measurement data were reduced to the series of graphic compilations included here as tables 6-1 through 6-4.

When recording the aforementioned measurement tapes, UNIVAC's target generator routine (module's mneomic is SFAPTS) was exercised. The Target Generator Routine was run on-line with the operational program and the version of this routine in OP-05 allowed the user to establish up to six controller targets via

TABLE 6-1. P-COUNTER DISTRIBUTION/TAPE 114

PROGRAM NAME	RANGE	NUMBER OF SAMPLES	PERCENT DISTRIBUTION
EXEC	001400-001421	781	85.64
PWTIE	001422-001533	0	0.00
COMMSR	001534-004274	0	0.00
DAS	004275-006121	85	9.31
TRACKB	006122-013557	3	0.33
KIPZ	013575-015055	5	0.55
CPSE	015056-016104	2	0.22
CTYPX	016105-017066	0	0.00
MTFPY	017104-017550	0	0.00
MTINTY	017551-017710	0	0.00
COMMSR	035547-035611	0	0.00
SFAPTS	036352-037663	29	3.18
ENRINC	047112-050457	0	0.00
ENROTC	050460-051336	1	0.11
ENINTC	051337-051657	0	0.00
AOFSTL	052200-052633	6	0.66
STOPE	052634-053212	0	0.00
DPEEXF	053213-053320	0	0.00
MTIPF	053325-053527	0	0.00
DATAEXT	053533-055525	0	0.00
MTI6CF	057217-057351	0	0.00
TMSE	057352-057543	0	0.00
PRINT	060000-060644	0	0.00

TOTAL SAMPLES 912
MAXIMUM NUMBER OF TARGETS 16

TABLE 6-2. P-COUNTER DISTRIBUTION/TAPE 284

PROGRAM NAME	RANGE	NUMBER OF SAMPLES	PERCENT DISTRIBUTION
EXEC	001400-001421	2719	84.18
PWT1E	001422-001533	0	0.00
COMMSR	001534-004274	2	0.06
DAS	004275-006121	337	10.43
TRACKB	006122-013557	31	0.96
KIPZ	013575-015055	14	0.43
CPSE	015056-016104	6	0.19
CTYPX	016105-017066	2	0.06
MTFPY	017104-017550	0	0.00
MTINTY	017551-017710	0	0.00
COMMSR	035547-035611	0	0.00
SFAPTS	036352-037663	112	3.47
ENRINC	047112-050457	0	0.00
ENROTC	050460-051336	1	0.03
ENINTC	051337-051657	0	0.00
AOFSTL	052200-052633	6	0.19
STOPE	052634-053212	0	0.00
DPEEXF	053213-053320	0	0.00
MTIPF	053325-053527	0	0.00
DATAEXT	053533-055525	0	0.00
MTI6CF	057217-057351	0	0.00
TMSE	057352-057543	0	0.00
PRINT	060000-060644	0	0.00

TOTAL SAMPLES 3230
MAXIMUM NUMBER OF TARGETS 19

TABLE 6-3. P-COUNTER DISTRIBUTION/TAPE 469

PROGRAM NAME	RANGE	NUMBER OF SAMPLES	PERCENT DISTRIBUTION
EXEC	001400-001421	2605	86.83
PWT1E	001422-001533	0	0.00
COMMSR	001534-004274	0	0.00
DAS	004275-006121	240	8.00
TRACKB	006122-013557	10	0.33
KIPZ	013575-015055	12	0.40
CPSE	015056-016104	13	0.43
CTYPX	016105-017066	0	0.00
MTFPY	017104-017550	0	0.00
MTINTY	017551-017710	0	0.00
COMMSR	035547-035611	0	0.00
SFAPTS	036352-037663	112	3.73
ENRINC	047112-050457	0	0.00
ENROTC	050460-051336	0	0.00
ENINTC	051337-051657	0	0.00
AOFSTL	052200-052633	8	0.27
STOPE	052634-053212	0	0.00
DPEEXF	053213-053320	0	0.00
MTIPF	053325-053527	0	0.00
DATAEXT	053533-055525	0	0.00
MTI6CF	057217-057351	0	0.00
TMSE	057352-057543	0	0.00
PRINT	060000-060644	0	0.00

TOTAL SAMPLES 3000
MAXIMUM NUMBER OF TARGETS 2

TABLE 6-4. P-COUNTER DISTRIBUTION/TAPE 1227

PROGRAM NAME	RANGE	NUMBER OF SAMPLES	PERCENT DISTRIBUTION
EXEC	001400-001421	1650	85.54
PWT1E	001422-001533	0	0.00
COMMSR	001534-004274	7	0.36
DAS	004275-006121	171	8.86
TRACKB	006122-013557	71	3.68
KIPZ	013575-015055	14	0.73
CPSE	015056-016104	10	0.52
CTYPX	016105-017066	0	0.00
MTFPY	017104-017550	0	0.00
MTINTY	017551-017710	0	0.00
COMMSR	035547-035611	0	0.00
SFAPTS	036352-037663	0	0.00
ENRINC	047112-050457	0	0.00
ENROTC	050460-051336	1	0.05
ENINTC	051337-051657	0	0.00
AOFSTL	052200-052633	4	0.21
STOPE	052634-053212	1	0.05
DPEEXF	053213-053320	0	0.00
MTIPF	053325-053527	0	0.00
DATAEXT	053533-055525	0	0.00
MTI6CF	057217-057351	0	0.00
TMSE	057352-057543	0	0.00
PRINT	060000-060644	0	0.00

TOTAL SAMPLES 1929
MAXIMUM NUMBER OF TARGETS 29

keyboard entry and displayed these targets on the DEDS. This routine provides the capability of switching back and forth from the simulated mode (i.e., user-generated targets) and the operational mode. Measurements contained on these tapes were collected in this fashion.

For tape 114, there are a total of 912 samples, with 781 being recorded within the executive routine and 131 samples (see table 6-1) in various program modules. The time spent in the Executive for this measurement run is 85.64 percent. Of the 14.36 percent busy time, 12.49 percent is spent in two modules, DAS and SFAPTS. The remaining 1.87 percent of busy time was spent in the TRACK B, KIPZ, CPSE, ENROTC, and AOFSTL modules, i.e., the remainder of the program modules imposed a minimal burden on the system.

Additional P-Counter Distribution Graphs are shown in tables 6-2 to 6-4.

6.2.2 I/O Channel Activity

The IOP is capable of communicating with peripheral equipment over any and all of 16 I/O channels concurrently with execution of IOP programs. Once initiated by a programmed instruction, operational proceed toward termination asynchronously with respect to the program modules. I/O instructions are executed in Control Memory. Table 6-5 lists the channel arrangements for OP-Ø5. The I/O portion of Control Memory in figure 6-9, is structured into 4 groups of 16 I/O channel locations.

Since I/O channel activity is gated through Control Memory, the Sampler Monitor measures the activity within a given sample (i.e. on a per-interrupt basis) by capturing the contents of Control Memory twice, initially upon entering, and again immediately before exiting. The Data Reduction-and-Analysis Program subsequently processes these measurements by comparing the two readings within a sample, summing and recording detected changes. Figure 6-10 tabulates a run of Control-Memory measurement data. The run consists of 500 samples depicting the level of activity for the 16 channels.

TABLE 6-5. IOP CHANNEL

IOP CHANNEL NUMBER	PERIPHERAL EQUIPMENT OR SUBSYSTEM	CHANNEL TYPE*	RELATIVE PRIORITY
0	Beacon DAS (input only)	B	Highest
1	ICA	B	
2	MTS	B	
3	CT Adapter	B	
4	UNISERVE VI C Tape Unit	A	
5	9300	A	
6	Unassigned	A	
7	DEDS Console	A	
8	DEDS Console		
9 - 15	Unassigned	A	Lowest

* Type A is external channel; Type B is internal channel.

CONTROL MEMORY ADDRESSES	31	30	29	28	27 18	17 15	14 Ø	
ØØ		d				INPUT CHAN	Ø CHAIN ADRS	
⋮								
15		d				INPUT CHAN	15 CHAIN ADRS	
16		d				OUTPUT CHAN	Ø CHAIN ADRS	
⋮								
31		d				OUTPUT CHAN	15 CHAIN ADRS	
32	W	X	Y	Z	INPUT CHAN WORD COUNT	Ø	CURRENT ADRS	BUFFER CONTROL WORD OR EXTERNAL FUNCTION WORD
⋮								
47	W	X	Y	Z	INPUT CHAN WORD COUNT	15	CURRENT ADRS	
48	W	X	Y	Z	OUTPUT CHAN WORD COUNT	Ø	CURRENT ADRS	
⋮								
63	W	X	Y	Z	OUTPUT CHAN WORD COUNT	15	CURRENT ADRS	

LEGEND:
d = don't care
W = 1 when BCW is part of a chain
X = 1 when chain command is EF
Y = Ø for upper halfword transfer
Y = 1 for lower halfword transfer
Z = Ø when EF specifies whole word transfer
Z = 1 when EF specifies halfword transfer

Figure 6-9. Control-Memory Word Format

ASSIGNMENT	CHANNEL	INPUT CHAIN	OUTPUT CHAIN	INPUT BCW	OUTPUT BCW
DAS	ØØ	Ø	Ø	52	Ø
ICA	Ø1	Ø	Ø	Ø	Ø
MTS	Ø2	Ø	Ø	Ø	Ø
CT ADAPTER	Ø3	Ø	Ø	Ø	Ø
VI C	Ø4	Ø	Ø	Ø	Ø
9300	Ø5	Ø	Ø	Ø	Ø
UNASSIGNED	Ø6	Ø	Ø	Ø	Ø
DEDS	Ø7	Ø	12	Ø	395
DEDS	Ø8	Ø	456	Ø	457
UNASSIGNED	Ø9 ... 15	Ø ... Ø	Ø ... Ø	Ø ... Ø	Ø ... Ø

Figure 6-10. I/O Channel Activity

It should be noted that measurements relating to the Monitor's data-recording phase; i.e., use of the VI C magneitc-tape unit, was not detected because of synchronization of the recording phase with the Sampler Monitor Interrupt. Also of interest is the activity detected on Channel 0, DAS real-time inputs to ARTS. This value indicates that the data-recording phase was interrupted by the DAS demand program module 10.4 percent of the time. This percentage of interruptions correlates with the DAS demand program module's utilization figures as obtained from other Sampler Monitor runs (see tables 6-1 to 6-4) exercised similarly in the simulation modes.

7. EVALUATION OF PROTOTYPE MEASUREMENT TOOLS

In this section, the two prototype measurement tools are assessed with respect to their applicability within the context of the ARTS III Single-Beacon Tracking Level System.

7.1 SYSTEM BURDEN

7.1.1 Core Memory Requirements

These core requirements are negligible, constituting less than 0.5 percent of the operational program.

7.1.2 IOP Usage

IOP usage for both measurement tools is minimal. The Executive Scheduler-tracing Monitor usage is about 100 ms per execution, resulting in a 1.0-percent burden. Sampler Monitor usage is 2.15 ms for each Monitor-Clock interrupt, with interrupts set to occur twice per second, resulting in a burden of only 0.43 percent.

7.1.3 Magnetic-Tape Usage

The commitment of a magnetic tape to record measurement data is not a serious constraint since the MTS is available at all sites. Although the ARTS III Data-Extractor Module, which may be exercised as part of the Operational Program, uses the MTS, the module also provides a special on-line recording feature for other users. Even with this capability, there should be no necessity to attempt both a data, extraction run and a measurement run simultaneously.

7.1.4 Operational Interface

Execution of the measurement-tool software imposes at most a 1 percent burden on the operational program. This burden can hardly have an appreciable effect on the timing of the flow of the operational program.

It should be noted that CPU and I/O operations are concurrent within the ARTS DPS. Therefore, relative phases of operations could be altered by any heavy measurement burden on CPU activity alone or by an uneven CPU and I/O activity. As previously stated, this is not the case with the prototype measurement tools.

7.2 MONITOR LOCKOUT/SYNCHRONIZATION

A serious problem exists in the Sampler Monitor in that measurements may not be random, but may be correlated with the manner in which the monitor gains control. For example, in a real-time system, the Executive Control Module may inhibit the monitor from receiving control during certain operations. These non-interruptable operations may then be falsely represented as not having occurred.

The basic ARTS III program does not lock out the Sampler Monitor, but nevertheless, imposes the constraint that the data-collection phase must not occur during execution of the DAS Demand-Program Module.

It should also be noted that measurements relating to the data-recording phase; i.e., use of the MTS, have not been captured because of synchronization with the Sampler Monitor interrupt. Although MTS usage impacts only slightly on I/O activity, means for its measurement should be provided. One such means is for the Sampler Monitor to gain control by a random interrupt. Use of a Hardware Monitor would be a better means for obtaining such data.

8. SUMMARY AND RECOMMENDATIONS

8.1 SUMMARY

Technical literature and commercially available products encompassing software, hardware, and hybrid monitors were analyzed to determine current computer systems performance-measurement techniques. These techniques were evaluated within the context of the ARTS III Single-Beacon Tracking Level System. The characteristics of the ARTS III Operational Program, the ARTS DPS, and support software were studied, and two prototype software monitors using the event-driven (Executive Scheduler Tracing Monitor) and the time-driven (Sampler Monitor) measurement techniques were developed, tested, and exercised at the ARTS III Test-Bed Facility in Minneapolis MN. These prototype measurement tools are specific to ARTS III, with the Sampler Monitor using the ARTS IOP Monitor-Clock interrupt.

Preliminary data reduction and analysis of measurement data obtained by these tools generally during non-peak airport loading and with minimal DEDS use depicted a CPU utilization of 20 percent with one program module (the DAS demand module) alone accounting for 16.3 percent CPU utilization.

The tools were evaluated in terms of their applicability and impact on the ARTS III Single-Beacon Tracking Level System. Use of a hardware monitor was suggested to complement certain software measurements, particularly those of I/O channel and peripheral utilization.

8.2 RECOMMENDATIONS

a. The Sampler Monitor should be upgraded to a pre-operational status and integrated into the current version of the Basic ARTS III Single-Beacon System. Its data-recording phase should use the special on-line recording feature of the Data Extractor Module. The monitor should be capable of obtaining either P-counter readings or I/O channel-activity measurements. I/O measurements should be obtained at the time of the Monitor-Clock interrupt unless the interrupt occurs during the execution of a demand-program module, in which case control should be returned to the interrupted demand program module before collecting data for that sample.

b. A hardware monitor should be used to complement measurements obtained by the software monitors. Specific measurements should include I/O channels utilization, CPU-I/O overlap, concurrent I/O utilizations, and CPU utilization.

c. Performance-measurement data relating to the Basic ARTS III Single-Beacon System should be obtained at the ARTS III Test Bed Facility in Atlantic City NJ (NAFEC) by means of the upgraded Sampler Monitor. The operational program should be exercised under varying aircraft loads in both an operational and a simulation mode. Operational mode-measurement data should be collected by means of live aircraft targets only. Simulation mode-measurement data should be collected through the use of the Target-Generator Routine, exercised on-line with the operational program to provide the means simultaneously to process both live and simulated targets.

Data reduction and analysis listings of measurement runs should be scrutinized by FAA and TSC personnel. Areas for improvements should be identified and estimates should be made relating to corresponding processing time reductions, memory savings, and implementation costs.

d. The Sampler Monitor should be adapted for the ARTS III Dual-Beacon System. Similarly, this should be exercised at NAFEC for purposes of measurement-data collection, reduction, and analysis. Again, software areas of improvement should be identified and corresponding relevant estimates should be generated.

e. Software-measurement tools should be developed for the ARTS enhancement multiprocessor environment and the parallel processor activity.

f. Consideration should be given to the development of Software-measurement tools for the ARTCC.