AD-A048 022 WEAPONS RESEARCH ESTABLISHMENT SALISBURY (AUSTRALIA) F/G 14/2

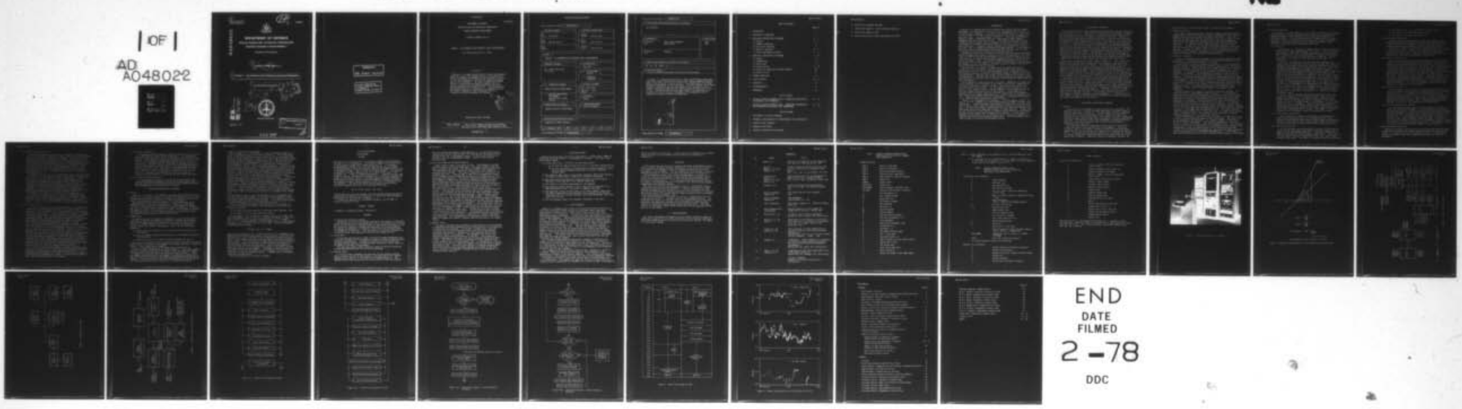
AUTOCELL: AN AUTOMATED HIGH FREQUENCY RADIO INTERFEROMETER.(U)

JUN 77 D N WARREN-SMITH, N J STEER

UNCLASSIFIED WRE-TR-1644(A) NL

1 OF 1

AD A048022



END

DATE FILMED

2-78

DDC

WRE-TR-1644 (A)

AR-000-904

AUSTRALIA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS RESEARCH ESTABLISHMENT

SALISBURY, SOUTH AUSTRALIA

TECHNICAL REPORT 1644 (A)

AUTOCELL: AN AUTOMATED HIGH FREQUENCY RADIO INTERFEROMETER

D.N. WARREN-SMITH and N.J. STEER

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Approved for Public Release

JUNE 1977

COPY No. 29

UNCLASSIFIED

AR-000-904

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS RESEARCH ESTABLISHMENT

TECHNICAL REPORT 1644 (A)

AUTOCELL: AN AUTOMATED HIGH FREQUENCY RADIO INTERFEROMETER

D.N. Warren-Smith and N.J. Steer

SUMMARY

Autocell is a computer-controlled h.f. radio interferometer employing a single twin channel receiver for automatically taking contemporary measurements of the direction of arrival of up to ten transmissions of different frequencies propagated via the ionosphere. The basic hardware and software features of the system are described together with the results of preliminary measurements made with the system during acceptance trials early in 1976. System limitations which might restrict its usefulness as a research tool for the study of ionospheric radio propagation and h.f. transmitter locating techniques are reported.

POSTAL ADDRESS: The Director, Weapons Research Establishment, Box 2151, G.P.O., Adelaide, South Australia, 5001.

UNCLASSIFIED

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1 DOCUMENT NUMBERS		2 SECURITY CLASSIFICATION	
AR Number:	AR-000-904	a. Complete Document:	Unclassified
Report Number:	WRE-TR-1644(A)	b. Title in Isolation:	Unclassified
Other Numbers:		c. Summary in Isolation:	Unclassified

3 TITLE

AUTOCELL: AN AUTOMATED HIGH FREQUENCY RADIO INTERFEROMETER

4 PERSONAL AUTHOR(S):	5 DOCUMENT DATE:
D.N. Warren-Smith and N.J. Steer	June 1977
	6 6.1 TOTAL NUMBER OF PAGES 32
	6.2 NUMBER OF REFERENCES: 14

7 7.1 CORPORATE AUTHOR(S):	8 REFERENCE NUMBERS
Weapons Research Establishment	a. Task: DST 74/06
	b. Sponsoring Agency: RD72
7.2 DOCUMENT (WING) SERIES AND NUMBER Applied Physics Wing TR-1644	9 COST CODE: 314678

10 IMPRINT (Publishing establishment):	11 COMPUTER PROGRAM(S) (Title(s) and language(s))
Weapons Research Establishment	

12 RELEASE LIMITATIONS (of the document):

Approved for Public Release

12.0	OVERSEAS	NO		P.R.	1	A		B		C		D		E	

Security classification of this page: UNCLASSIFIED

Security classification of this page: UNCLASSIFIED

13 ANNOUNCEMENT LIMITATIONS (of the information on these pages):

No limitation

14 DESCRIPTORS:

a. EJC Thesaurus Terms	Radio interferometers Radio waves	
b. Non-Thesaurus Terms	Autocell	

15 COSATI CODES:

1402
2014

16 LIBRARY LOCATION CODES (for libraries listed in the distribution):

SW SR SD AACA NL

17 SUMMARY OR ABSTRACT:
(if this is security classified, the announcement of this report will be similarly classified)

Autocell is a computer-controlled h.f. radio interferometer employing a single twin channel receiver for automatically taking contemporary measurements of the direction of arrival of up to ten transmissions of different frequencies propagated via the ionosphere. The basic hardware and software features of the system are described together with the results of preliminary measurements made with the system during acceptance trials early in 1976. System limitations which might restrict its usefulness as a research tool for the study of ionospheric radio propagation and h.f. transmitter locating techniques are reported.

Security classification of this page: UNCLASSIFIED

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Autocell is a computer controlled interferometer facility for the automated measurement of the direction of arrival of h.f. radio waves which have been reflected by the ionosphere. The study of the propagation of h.f. radio waves via the ionosphere has been of interest in Australia as well as elsewhere for a great many years. See, for example, reference 1. This type of propagation displays a number of phenomena which are of importance to high frequency communications and to direction finding. The availability of comparatively inexpensive general purpose digital computers has made it feasible to automate a technique of ionospheric measurement which has previously required tedious manual procedures. Automation greatly speeds up the accumulation of data on which the study of ionospheric propagation phenomena depends. It also makes it possible to carry out more complex experiments than have been possible before; for example by providing the capability of frequency agility.

The software written for the Autocell system provides an interactive keyboard operating program which permits selection of up to ten frequencies in the range 2 MHz to 13 MHz for successive measurements, with a choice of format for real-time display on a teletype machine and an independent choice of format for data storage on magnetic tape. The operating program incorporates the use of an interpretive instruction sequence which can be entered from the teletype keyboard. The program also uses the computer interrupt facility to increase the rate of making measurements as much as possible.

After initial set up, which is minimal and after typing the required instructions into the computer from the teletype keyboard, the system will automatically carry out all the required operations of: tuning the system to the selected frequency, calibration, measurement sequence, computation for real-time processing if required, data storage and data print-out for display on the teletype machine. The above operations are then automatically repeated with the next frequency selected and so on, according to the instruction sequence entered into the computer.

The following real-time processing is available: computation of azimuth and elevation angles, with an estimate of the range of the source; computation of N-S and E-W components of angle of arrival; individually selectable digital data smoothing for each channel; and the formation of a histogram for one channel of the computed angles of arrival together with the computation of the mean and standard deviation values of these angles. The maximum rate of operation under favourable conditions with the current state of development is approximately four complete measurements per second if only one frequency is in use. Under unfavourable conditions a measurement is automatically terminated if not completed within approximately three seconds.

Figure 1 is a photograph of the equipment. A PDP-8L computer occupies the rack on the left, together with associated peripheral equipment including a dual DECtape unit. Control equipment with computer interface and subsystems interface circuitry, power supply and HP3330A frequency synthesizer occupy the centre rack. The Racal twin channel communications receiver type RA153 together with measurement and receiver subsystems occupies the right hand rack. A small table for the convenience of the operator is normally placed adjacent to the teletype machine, but was removed for the benefit of the picture. A small amount of equipment associated with the interferometer aerial interface is housed in a separate rack which does not appear in the picture. The interferometer aerial array occupies a field near the equipment building.

2. PRINCIPLES OF OPERATION

The interferometer measurement technique used for Autocell has been described in references 2, 3 and 4. The method can be understood by reference to figure 2. The interferometer consists basically of two pairs of horizontal dipole aerials with separation (d) that are accurately surveyed into position. One pair is sited in a North-South direction and the other pair in an East-West direction. The separation of the dipoles in each pair is 73.15 m (240 ft). The X's on the N-S and W-E axes shown schematically in figure 2 represent the centre points of the aerials. A measurement of the phase differences of the signals appearing in each of the two pairs of dipoles is sufficient to determine the direction of arrival of the incoming wave at the selected frequency, provided the frequency is sufficiently low or that signals are arriving from near the zenith. For higher frequencies and oblique signals an ambiguity arises from grating lobes due to the spacing of the dipole pairs. The ambiguity is resolved by providing an additional two pairs of aerials at one quarter of the spacing of the main array.

Reference to figure 2 shows that the bearing ϕ and elevation angle θ can be computed from the measured phase angles δ_{NS} and δ_{EW} in two stages, after correcting for the ambiguity in these angles if necessary. The intermediate angles α and β defined in the figure are first computed. From these, the bearing and elevation angles are computed. The standard PDP8 23-bit format floating point package is used to carry out all of the required steps of ambiguity correction and computation including the determination of the correct quadrant for the bearing angle. The conventions used for the definition of the respective angles can be seen in figure 2, where the bases of the arrows give the zero degree positions and the arrow heads give the sense of increasing angle. Bearing angles are measured from 0° to 360° in a clockwise sense from due North.

In the practical realisation of the interferometer each horizontal dipole as described so far actually consists of two crossed dipoles arranged at 45° to the North-South direction. These crossed dipoles are connected with a phasing circuit to form a circularly-polarized antenna. The direction of polarization can be selected remotely. The horizontal dipoles have a polar diagram which is directed vertically thereby ensuring that ionospherically propagated signals are given preference over ground wave signals. Furthermore, only six crossed dipole aerials are used since the short base line pairs can share one dipole each with the long base line pairs. In principle, therefore, the basic requirement is to make a sequence of phase measurements. In practice, there are a number of complications which have to be taken into account and these are described in more detail in later sections.

3. FUNCTIONAL DESCRIPTION OF HARDWARE

3.1 General

The Autocell system equipment is made up of four main subsystems: the computer, controller, receiver and phase measurement subsystems (shown in block schematic form in figure 3). The dual channel receiver subsystem amplifies the selected high frequency (h.f.) transmission received by selected pairs of aerials and converts these signals to 100 kHz signals, the differential phase angle between which is measured by the phase measurement subsystem. The operation of the phase measurement subsystem and certain aspects of the receiver subsystem such as signal level adjustment is controlled by the controller.

The controller contains a programmable microcontroller and interface circuits for each of the subsystems and for the computer. The microcontroller controls the complete sequence of calibration and measurement operations and also other sequences of operations, as required for specific tasks. The operation of the microcontroller can be initiated and observed on a manual control and display panel which can be seen at the top of the centre rack in figure 1. When the system is in operation, however, the microcontroller is itself directly under the control of the computer.

3.2 Computer subsystem

The computer subsystem comprises a Digital Equipment Corporation PDP-8L computer(ref.5) with 8K core memory, an ASR33 teletypewriter and a TU56 dual DECtape transport with associated TC08 DECtape controller. The interconnection of these units and the controller can be seen in figure 4, which shows the Autocell controller sharing the daisy chain input/output bus structure of the computer with the memory extension unit and the DECtape controller. All subsystem control then takes place from the Autocell controller. The fact that the Autocell and DECtape controllers share the same bus means that the computer cannot interleave the operation of these two units. However, in practice, this is not a severe restriction as the time lost when the system is in operation is of the order of one or two seconds per DECtape storage operation every few minutes.

3.3 Controller subsystem

A very much simplified block diagram of the controller subsystem is given in figure 5. The interface between this subsystem and the manual control and display panel has been ignored in this figure.

It can be seen at the top of figure 5 that there is a flow of parameters from the computer through appropriate interface (selector gate) circuitry to a set of registers. These registers hold information such as the selected frequency, attenuator settings and initialisation parameters (i.e. switch settings). This information is then available to the subsystems until changed by the computer. Following down the diagram, it can be seen that there is a similar flow of data and parameters from the subsystems to the computer. The phase measurement data (and also sample time and other data) is accumulated in a set of registers from which the information can be passed to the computer. The data transfer process is initiated by the microcontroller when a complete set of data is assembled and occurs through the direct memory access facility of the computer into a preselected buffer area in the computer's memory. The computer reads parameter information (final parameters or logic switch settings) through its programmed transfer capability.

The microcontroller is shown at the bottom of the block diagram. The microcontroller is a programmable sequencing device. It can generate a number of control pulses on individually selected lines and it can perform conditional as well as unconditional transfers to any step in the sequence by means of a second set of individually selected lines, which sense the conditions to be tested. The microcontroller thus has the capability of responding to circumstances as they arise and to switch to a new sequence step or loop back to a previous sequence step as required. In some cases, the microcontroller will initiate a sub-sequence controlled within a subsystem. In this case, the conditional branching facility is used to execute a waiting loop until a flag signal from the subsystem is set. To avoid a possible indefinitely long waiting time, a time limit test is included in the waiting loop in a number of cases. At the expiry of the time limit, the microcontroller program exits and signals the computer.

The microcontroller circuitry is based on an INTEL 1702 PROM device which provides a fixed non-volatile memory to hold the program. This device can be reprogrammed in the laboratory. An assembler program is available to assist in firmware development. This assembler program will run on the Autocell computer or any other similar PDP-8 computer system. The assembler will accept a source file generated with the operating system software of the computer(ref.6), and will produce both a fully coded octal and decimal listing of the microcontroller program and a specially coded paper tape which can be fed directly into an INTEL PROM programmer(ref.7). The amount of time and frustration saved over manual coding and PROM loading is considerable.

3.4 Receiver subsystem

The receiver subsystem comprises a twin channel receiver and the following associated units: aerial multicoupler units, aerial switching unit, dual matched attenuator, digital tuning circuits, gain balance control and attenuator control. The latter three units, although functionally part of the receiver subsystem, are located physically with the phase measurement subsystem. The block diagram in figure 3 should be referred to when reading the following sections describing these units.

3.4.1 Receiver

The receiver is a Twin Channel Communications Receiver, Type RA153, manufactured by RACAL Communications Inc.(ref.8). This receiver covers the frequency range 1 MHz to 30 MHz and provides two separate signal paths, balanced to 1 dB in amplitude and 15^{o} in phase, to produce two i.f. signals at 100 kHz, at which the phase is measured. The two channels are electronically linked and tuned by the same local oscillators.

In view of the magnitude of the phase and gain imbalances and because these vary with both receiver control settings and signal level, a number of calibration and control functions are necessary to ensure that phase measurements are accurate to better than 2^{o}. Before each set of phase measurements (for a particular signal frequency), a calibration phase measurement sequence is entered in which a calibration signal at the selected frequency is applied to both inputs of the receiver and the gain imbalance is removed by the gain balance control prior to the phase imbalance being measured. This calibration measurement is subsequently subtracted from the following aerial phase angle readings to obtain the true phase angle data. In addition, in order to reduce the differential phase angle shift due to signal level variations to an acceptable level, measurements are taken only when the two i.f. signals fall within a 10 dB dynamic range. Since this would otherwise result in excessive data dropouts for a signal with greater dynamic range, a twin channel phase matched r.f. attenuator ahead of the receiver is controlled to maintain the i.f. signal levels within the desired range.

The only receiver settings controlled by Autocell are the tuning signals for frequency selection and the channel 2 gain control to balance the channel gains. The other receiver controls of most concern, which are set manually prior to operation of the system at present, are the r.f. aerial tuning, r.f. attenuator, r.f./i.f. gain control and the i.f. bandwidth. The main restriction imposed by the necessity to manually set the positions of these controls prior to system operation is with respect to the dynamic range of signal levels which can be accommodated by the system. This range is at present limited to the 60 dB dynamic range of the automatic attenuator.

3.4.2 Aerial multicoupler units

Each of these units comprises two identical isolating amplifiers each of which enables one aerial to be connected to up to four receivers without mutual interference, thereby permitting operation of Autocell in parallel with other systems from the same set of aerials. The unit also provides 10 dB gain and increases system sensitivity.

3.4.3 Aerial switching unit

This unit provides for the connection of either a selected pair of aerials or the calibration signal source to the dual channel receiver inputs via the dual matched attenuator. Switching is achieved in under 10 ms by means of mercury wetted bistable relays. The selection of relay contact closures is determined by three d.c. signal levels during a strobe pulse. The three d.c. signals control the selection of

(a) the signal source, i.e. calibration or aerial array,

(b) the North-South or East-West aerials, and

(c) the widely or narrowly spaced aerials.

3.4.4 Dual matched attenuator

The dual matched attenuator operates under the control of the attenuator control unit situated in the phase measurement subsystem. Both channels of the attenuator consist of four 'pi' sections of swtiched attenuation providing 4,8,16 and 32 dB of attenuation. Switching is accomplished using mercury wetted bistable relays and is controlled by four d.c. signal levels determining the status of each of the four switches in the two channels and a strobe pulse for establishing a new setting. Thus the attenuation of both channels is controlled in 4 dB steps over a range of 0 dB to 60 dB.

3.4.5 Digital tuning circuits

These circuits provide the two tuning signals required to tune the receiver to a frequency specified by the controller. The two tuning signals control the megahertz and kilohertz contents of the signal selected by the receiver, which uses the Wadley system of band selection. The tuning signals automatically tune the receiver to the frequency specified by 6 BCD digits provided by the controller, two of which determine the megahertz tuning (1 to 30 MHz) and four of which determine the kilohertz tuning in 0.1 kHz steps within the range 0 kHz to 999.9 kHz. The MHz tuning signal tunes to a new setting within 20 ms and the kHz tuning signal within 200 ms. A frequency "stable" flag is set when the kHz tuning signal frequency is locked to the value specified (except for the 40 ms after receipt of a clear flag signal from the controller). The clear flag signal is applied when a new frequency is called for by the controller.

3.4.6 Gain balance control

The gain balance control provides the means for equalising the gain of the two channels of the receiver, the need for which was explained in Section 3.4.1. On command from the microcontroller the gain balance control monitors the two i.f. signals and adjusts the gain of channel 2 to equalise the i.f. signal levels. The gain imbalance of the receiver is specified as ± 1 dB and the controller provides more than 4 dB variation in channel 2 gain. When gain balance has been achieved, a flag is set for reading by the microcontroller.

3.4.7 Dual matched attenuator control

The two-channel matched attenuator can be operated in either of two modes, the Lock and Search modes. In the Lock mode, the attenuator setting remains fixed at that pertaining when the Lock mode was applied. In the Search mode, the control circuit seeks to bring or maintain the amplitude of the i.f. signals within a given range as described in Section 3.4.1. A flag capable of being read by the controller is set when the signal cannot be brought within this range. The mode of operation of the attenuator control can be determined from the controller or, by means of a switch, from the card itself. The attenuator setting can also be set and read from the computer via the controller.

3.5 Phase measurement subsystem

The phase measurement subsystem, an early version of which was described in reference 13, performs the primary measurement function of the Autocell system. In addition to the phase measurement circuits, it comprises the data consolidation circuits and a frequency synthesizer and associated attenuator.

3.5.1 Phase measurement circuits

The phase difference between the two i.f. signals is measured on a cycle to cycle basis by counting the number of pulses of a clock between zero cross-over points on the two i.f. signals. In order that this should provide a direct measurement of the phase angle and to avoid errors resulting from variations in the i.f. signal frequency, the clock is controlled to be a fixed multiple of the i.f. signal frequency for variations of up to 8% in the nominal frequency of 100 kHz. Since the factor by which the clock is a multiple of the i.f. is 256, a phase difference of 360^o is represented by 256 bits in this phase measurement system. The measurement resolution of 1 bit (of phase) is equivalent to 1.4^o.

To reduce errors due to receiver differential phase shift with signal level variations to an acceptable amount, measurements are taken only when both i.f. signal levels fall within a given range. Moreover, in an attempt to ensure that only quasi-unimoded propagation is considered, measurements are restricted to those times when the amplitudes are equal to within some preset tolerance, which is small in comparison to that permissible under the range restriction just mentioned. To further limit the measurements to single moded conditions of transmission the readings are only utilised when a given number of preceding cycles have met this amplitude equality test. This wavefront test number can be selected in the range 0 to 7.

In addition to making these tests (signal in 'amplitude' window, amplitude equality, wavefront tests), the phase measurement system contains a circuit which determines whether the i.f. signal levels are above the receiver noise level, thereby indicating the presence of signal. For i.c.w. transmissions this is used to strobe measurements.

3.5.2 Data consolidation

The function of the data consolidation circuits is to compound and reduce the raw phase measurement results, which can occur at a rate of as much as one measurement every ten microseconds, by deriving the mode and the median values. This is achieved by providing a hardware histogram circuit, which is readily achieved with random access memory, in which one memory cell is reserved for each of the 256 possible measurement values. The mode is the most frequently occurring value and is detected as that value for which the number of occurrences first exceeds a pre-selected number given by 32n + 31, where n(= 0 to 7) is the mode parameter and is computer selectable. Since phase measurement is circular without discontinuity at 0^o or 360^o, i.e. 0 or 256 phase units in the measurement system used, the median value is computed with respect to the mode. Moreover, in deriving the median value, the next successive value after values 254 units, 255 units and 256 units is taken as 1 unit because all the measurements are for signal paths of less than one wavelength and a reading of 254 units therefore corresponds to -2 units, 255 units to -1 unit etc. Taking account of this, the median value is derived by starting at a value 128 units less than the mode and accumulating a count of the number of occurrences of readings for successively higher values until the count equals one half the total number of readings taken. The value at which this occurs is taken as the median value.

It is these consolidated measurements, the mode and median values, which are transferred to the controller for display and thence to the computer for further processing and recording and display. Also transferred to the computer is the number of wavefront test failures occurring during the measurement, which is a measure of the signal to noise level pertaining during the measurement.

3.5.3 Frequency synthesizer

A programmable HP3330A frequency synthesizer provides the calibration signal and simulated signals during system tests. All programmable functions of the synthesizer can be controlled from the microcontroller program. The synthesizer output signal frequency can be set to 0.1 kHz resolution to any frequency within the range 0.1 kHz to 13,000.9 kHz within 2 ms. The upper limit of 13 MHz for the frequency synthesizer sets the upper frequency limit of operation for the system which would otherwise be 30 MHz. The signal level is not programmable and must be set manually. However, the signal can be switched off in so far as it affects the system by switching the frequency to zero and this facility is used during phase measurements on aerial signals to eliminate the possibility of interference from the calibration signal.

3.5.4 Calibration signal attenuator

A 50 Ω attenuator provides the control for the calibration signal level and should be set manually to match the incoming signal level to minimise delays resulting from switching of the dual matched attenuator. The attenuator has a range of 80 dB in 1 dB steps.

4. FUNCTIONAL DESCRIPTION OF SOFTWARE

4.1 General

Some idea of the scope of the AUTOCELL operating program (ACOP) has already been given. Its essential purpose is to enable the operator to control the system's operation whilst seated at a teletypewriter from which he has a good view of the equipment and can monitor each unit's performance.

The program has three modes of operation. The principal mode is the Command Mode and the two subsidiary modes are the Type and Search Modes. Transfer of control between the various modes is made through the keyboard and since the keyboard input interrupts the computer's operation, the operator has immediate control of the system at all times. The Type Mode is used for typing messages and in it the teletype merely echoes the characters typed. The Command and Search Modes will be discussed in turn.

4.2 Command mode

In this mode a line of characters, a Command Line, typed by the operator constitutes a sequence of commands to the system. However the characters are not acted upon, except for being stored in a buffer and typed, until receipt of a CARRIAGE RETURN character. To assist him in entering the desired command code correctly the operator is able via special keyboard commands to

(a) delete characters successively in a reverse direction from the last one entered;

(b) have the computer retype the line where this is desirable for operator clarification or

(c) abandon the entire line without having the computer act upon it.

In addition the teletype bell rings to warn the operator when only 10 character spaces remain to be filled in the command line and again when only 2 characters remain. Excess characters are ignored.

A list of characters usable in the command mode together with an indication of their interpretation is given in Table 1. Two of the commands, those for opening the Instruction and Display Lines, have their own subsets of commands and associated characters which are listed in Table 2. These two commands together with their sub-commands are entered on separate lines. The Instruction Line determines the operations performed when the Instruction Sequence is initiated and the Display Line determines the data stored and the data displayed when the Display Instruction is encountered during the execution of the Instruction Sequence.

When a command line is terminated i.e., when the CARRIAGE RETURN key is pressed, the computer proceeds to interpret the line. The actions which may be called for include the storing of control settings for measurements (shown as 'Store Parameters' in figure 6(a)), storing an instruction sequence or display sequence, opening or closing a file etc. When the system has been prepared for taking measurements, which involves at least the first three operations referred to above, the system can be activated with a special keyboard command: 'Start Instruction Sequence'. At this time the instruction sequence interpreter is entered (see bottom of figure 6(a)) and the instructions previously entered in the Instruction Line are executed in sequence. Some of the operations which might be executed in the process include the starting of the controller, the entry of data into a histogram, the insertion of a delay in the operation, the calling of the display sequence and a repetition of the entire instruction sequence. A flow chart showing what happens when the controller is started is given in figure 7. A full description of this and of the other operations is available in reference 14. When the display sequence interpreter is called, it executes the sequence of display operations previously entered in the Display Line. At the end of the display sequence, control is returned to the instruction sequence. A given instruction sequence may call the display sequence interpreter a number of times, for example, for each signal being observed. At the end of the instruction sequence, control is returned to the Command Mode.

From figure 6, Tables 1 and 2 and the above it will be apparent that a wide range of operating sequences is possible and that sequences can be readily set up and modified from the keyboard. To illustrate the form of the commands and the method of using this mode, a full description of which is given in reference 14, a small example will be given.

In this the assumed requirement is to take 100 sets of readings, for both the NS and EW sets of aerials, form a histogram of the 100 sets of readings and to print

(a) the mean and standard deviation of the phase angle measured; and,

(b) the number of sets of good readings obtained.

The measurement is to be taken for a signal frequency of 1.2 MHz; the phase measurement system is to be set to provide the median (as opposed to mode) value for display, using an overflow figure of 7 i.e. a mode of (32 x <u>7</u>) + 31 = 255 readings and a wavefront number of <u>6</u>; the dual matched attenuator is to be set to 12 dB i.e. (<u>3</u> x 4) dB. The latter parameters are entered first by typing:

1F012000 P076 A3 'RETURN'

where the first character, the 1, indicates that this is a Parameter line defining the status which the parameters specified later in the line are to taken when this line is referred to any in subsequent Instruction Line(s). The F, P and A together with the associated digits define the parameters as required above. Thus the frequency is specified to the 100 Hz resolution of the digital tuning system by the 6 digits following the character, F; the three digits following the character, P, specify three parameters, namely the statistic to be displayed (0 for median, 1 for mode), the overflow number and the wavefront number. Similarly the digit following the character, A, specifies the number of 4 dB increments of attenuation to be provided by the dual matched attenuator. 'RETURN' here, as elsewhere, signifies a carriage return.

The actual operation is activated by typing:

IC 100(1,H)D'RETURN'

D/# M'RETURN'

-'RETURN'

The first line is interpreted as an instruction sequence as determined by the letter 'I' at the beginning. The sequence commences with the clearing of the histogram storage area as specified by the 'C'. It continues, as determined by the 100 (1,H), with the taking of 100 sets of readings, for the measurement conditions previously specified in Parameter Line 1, and a histogram is formed. The 'D' calls the Display Sequence. This sequence is defined by the line commencing with a 'D' which in this case is the following line. Since no characters precede the '/' character in this line, no data is stored; the characters following the '/' character determine the format of the printout, which is a carriage return/line feed determined by the # character and a printout of the total number of readings, the mean of the readings and their standard deviation on one line, as specified by the 'M' character. The third line causes the execution of the specified instruction sequence and results in a printout of the form:

98 97 20.37 91.86 1.93 2.05

In this there are a pair of readings, the first of each referring to the N-S aerials and the second to the E-W aerials, for each of the three parameters specified by the 'M' character (see above).

To repeat the operation for a different frequency, say 10.8 MHz, it would be sufficient to type:

1F108000 'RETURN'

to change the frequency parameter, followed by:

-'RETURN'

to execute the instruction sequence.

A noteworthy facility which has been included in the software is that which allows the operator use of the Command Mode without interrupting the execution of the current instruction sequence except for any printout for which it calls. This allows the operator to perform such operations as listing parameters or changing the parameters or entering a line of text into the data buffer for storage on the data tape. Even the display or instruction sequences may be altered without interrupting the collection and storage of data.

4.3 Search mode

In this mode the receiver is tuned to successive stepped frequencies with the initial frequency and the frequency increment set from the keyboard before activating the operation. Thereafter the direction of the sweep can be reversed, whenever desired, by using the space bar and the rate of sweep can be varied by adjusting a potentiometer.

This operation replaces manual tuning but cannot be used for taking and storing measurements because of core store limitations.

4.4 Display buffer

A circular buffer arrangement has been used for data display printout. Data is entered into the circular buffer at the high speed of the computer operation and is fed out at low speed for the teletype printout. The operator should limit instructions for data printout to about one printout for every fourth measurement on each frequency (i.e. by use of the bracket construction) and the circular buffer will then prevent the page print from holding up the rate of measurement taking. If the circular buffer fills with data, the rate of measurement taking is limited by the teletype printout speed.

4.5 Core store usage and histogram formation

Figure 8 gives a map of core usage by ACOP. The 8K memory is divided into two fields of thirty two pages each. The usage of these fields and pages is shown in the figure. The portion of memory above the dotted line is transferred in and out of memory by certain parts of the computer's operating system software. This debars certain parts of the program from occupying this area. The last page in each field is permanently reserved for the computer system keyboard monitor which is an integral part of the operating system software. The Autocell Operating Program and buffer areas for parameters, command line, instruction sequence and display sequence, data, display and filters occupies the rest of field 1 except for the generalised output routine which performs the operations of storing data on tape via the output file buffer and handler in field 0 and also of opening and closing data files. Data processing routines occupy field 0. Included in the data processing routines is the histogram routine mentioned earlier. The histogram can be accumulated from any one parameter line. Actually two histograms are stored, one for the North-South phase readings and the other for the East-West phase readings. Each histogram consists of 256 bins, i.e., one for each possible phase reading. The histogram printout routine prints out all non zero lines of the histogram and computes and prints out the total number of readings, and the mean value and standard deviation of these readings for each histogram. Only successfully completed measurements are included in the histograms. A major complication which is taken into account in the program is the possibility that the mean value will occur near zero degrees or 360^{o}; correct values for the mean and standard deviation are computed in these cases. The possibility of the histogram overflowing is also taken into account. The histogram routine is of great value in checking system performance. The standard deviation figures provide a sensitive indication of the noise introduced by the receiver and measurement subsystems. The disadvantage of the histogram routine is the large amount of storage space which it requires both for data and for the routine itself.

4.6 Digital filter

The digital smoothing filter performs a similar function to the histogram in providing statistical smoothing, but with substantially less storage than is needed for the histograms. It provides a separate dual, two-stage filter for each of the ten parameter lines, each with an individually selectable time constant. The digital filter algorithm used has been described in detail in reference 9. The implementation of the filter effectively allows better presentation of the data. The azimuth and elevation computations take their data from the smoothed phase measurement values. The filter is activated by entering the filter parameter with a value between 0 and 7 in the parameter line. 0 corresponds to no filter action and in practice 4 is about the longest time constant filter parameter that would be used. The filter algorithm has a convenient property which avoids any difficulty when the phase readings vary through 0^{o} and 360^{o}. This is achieved in the assembly language subroutine that implements the smoothing filter algorithm.

5. SYSTEM LIMITATIONS

Whereas the system meets the design requirements, it suffers from a number of limitations which may restrict its usefulness for research. These are listed below without comment.

(1) System sensitivity is limited by the following factors:

(a) the lack of computer control over the r.f. band-pass tuning facility;

(b) the fact that tuning is accomplished by setting up nominally correct local oscillator frequencies and does not involve tuning for maximum signal.

(2) The frequency upper limit of the system's operation, which would otherwise be 30 MHz, is restricted to 13 MHz by the frequency synthesizer.

(3) The time allowed for completion of each operation initiated from the controller is the same and is not computer controlled.

(4) The duration of the phase measurements is not measured.

(5) The inequality between Channels 1 and 2 signal levels permitted in the amplitude equality test is not switch or computer selectable.

(6) The amplitude of the calibrate signal is not under computer control and can differ significantly from the signal level, thereby involving much switching of the dual matched attenuator and longer measurement times than need to be the case.

(7) The 60 dB dynamic range of the automatic attenuator is too small.

6. INITIAL RESULTS

Figure 9 is a computer plot of what is essentially the result of the first trial with the Autocell system carried out a few weeks after installation. The figure shows the bearing plots of three transmitting stations taken over approximately a two hour period. The vertical scale in each case is for a range of ten degrees of bearing. It can be seen that each station was situated in a different quadrant. The bearing fluctuations on this occasion were quite severe. The dashed line in the top diagram (for Broken Hill) represents the true bearing of this station with respect to the site of the Autocell system at St. Kilda in South Australia. The diagram for Lyndhurst shows a considerable offset from the true bearing of 122°. This was due to a fault which was discovered as a result of this trial. The data for Woomera are somewhat too sparse to be of use other than for demonstration but indicate the need for greater sensitivity which was subsequently improved by the addition of preamplifiers. The digital smoothing filter described earlier was used in plotting these results. The effect of the filter transient can be seen in the Woomera data where the trace recovers from a few off scale data points that were not rejected by the computer program.

The fluctuations and spread in bearing angle apparent in these plots are similar to those recorded by other observers, e.g. figure 1 of reference 10. Fluctuations with periods of approximately 20 min are commonplace. Essentially it is the presence of these fluctuations which is one of the motivations for a more detailed study of the angle of arrival of electromagnetic waves propagated via the F_2 layer of the ionosphere.

For a comparison with more recently published data, reference 11, figure 2, is quoted. Much the same observations apply to this reference as were mentioned with respect to the previous reference. This indicates some degree of consistency in the observed data both with time and with geographical latitude.

The results described for the Autocell system have all been obtained using c.w. transmissions. Developments are under way which will enable Autocell to respond to pulse transmissions and therefore will provide the means of propagation mode discrimination and selection. Some of the basic components of the Autocell system were used in a preliminary semi-automated version described in reference 12.

7. CONCLUSION

A description has been given of a computer-controlled interferometer facility which is capable of making automated measurements of the direction of arrival of a number of electromagnetic waves of different frequency that have been propagated via the ionosphere. The main components of the hardware system have been described and an outline of the operating program for the system given.

System automation enables fully calibrated measurements to be made at a faster rate than can be performed by manual methods and the frequency agility of the system provides the ability to carry out new experiments which have previously not been possible. It is anticipated that the system will assist in research into phenomena that are of interest in the fields of high frequency communication and direction finding.

The ability to store the data on magnetic tape is a considerable practical convenience since the data can subsequently be readily processed on a larger computer equipped with plotting facilities. Specific features of the data can then be reprocessed with varying procedures to bring out details of interest. The possibilities in this respect rapidly outpace the capabilities of equipment which requires manual handling of data.

The system described in this paper also provides a demonstration that the human operator is not indispensable as part of the measurement process. The automated installation can take over the routine operations which a human has previously been required to perform and the procedures are freed from the limitations imposed by tedium, inattentiveness and human error. The human operator can then apply himself to the specification of the experiment and the analysis of the results.

8. ACKNOWLEDGEMENTS

The design, development and commissioning of Autocell involved a number of people and in particular the authors would like to acknowledge the significant contributions made by Messrs W.A. Eason, R.M. Ellard, R.L. Farrell, G.E. Moore, G.J. Perry and R. Spragg.

REFERENCES

No.	Author	Title
1	Munro, G.H.	"Travelling disturbances in the ionosphere". Proc. Roy. Soc. A202, pp 208-223, 1950
2	Ross, W., Bramley, E.N. and Ashwell, G.E.	"A phase comparison method of measuring the direciton of arrival of ionospheric radio waves". Proc. I.E.E., 98, III, pp 294-302, July 1951
3	Treharne, R.F. McCue, C.G., Jeffrey, Z.R. and Hewett, B.S.	"Some characteristics of the propagation of skywaves over short ionospheric paths". Proc. I.R.E.E. Aust., pp 245-254, August 1965
4	Treharne, R.F.	"Vertical triangulation using skywaves". Proc. I.R.E.E. Aust., pp 419-424, November 1967
5	Digital Equipment Corporation	"The DIGITAL PDP-8/L users handbook". 1968
6	Digital Equipment Corporation	"OS/8 Handbook". (DEC-S8-OSHBA-A-D), 1974
7	Intel Corporation	"MCS-8 Micro computer set - 8008 Users Manual". March 1973
8	RACAL Communications Incorporated	"Operating Manual for twin channel H.F. communications receiver, type RA 153A".
9	Warren-Smith, D.N.	"A digital filter for data smoothing". WRE-TM-1191 (AP), October 1974, Unclassified
10	Bramley, E.N. and Ross, W.	"Measurement of the direction of arrival of short radio waves reflected at the ionosphere". Proc. Roy. Soc. London, Series A, 207, pp 251-267, 1951
11	Jones, T.B. and Spracklen, C.T.	"The correction of errors produced in H.F. direction finders by travelling ionospheric disturbances". Conference pre-print No. 173, on radio systems and the ionosphere. AGARD. 1976
12	Spragg, R.D.	"Fingerlance: A Semi-automatic H.F. direction of arrival and doppler measuring system for the study of local travelling ionospheric disturbances". WRE-TN-A234 (AP), March 1974, Unclassified
13	Moore, G.E. and Farrell, R.L.	"Experiments on Radio Phase Measurement with a Dual Channel Receiver". WRE-TN-1076 (AP), November 1974, Unclassified
14		"Autocell Handbook". Cybernetic Electronics Group, W.R.E. Unclassified

TABLE 1. AUTOCELL OPERATING PROGRAM (ACOP) - CHARACTERS RECOGNISED BY THE COMMAND LINE INTERPRETER

Command line mode

CTRL B	Revert to type mode
CTRL C	Return to KB Monitor
CTRL H	Hold continue data display
CTRL S	Stop Controller immediately
CTRL O	Stop listing or stop data typeout
CTRL U	Abort line
RUBOUT	Correct error
LINE FEED	Retype line
CAR RETURN	Line terminator, interpret line
ALT MODE	Continue after INS SEQ ? Character
A	Set attenuator n, m
CD	Call command decoder
CL	Close data file
D	Set display sequence
F	Set frequency
G	Set gain n, m
HC	Clear Histogram
HT	Type Histogram
I	Set Instruction Sequence
K	Set filter parameter K n, m
L	List parameters
M	Type total measurement count
O	Set Options n, m
P	Set Phase n, m
R	Set Height (km) for range
S	Start Search Mode
T	Type Data Lines n, m
X	Type 20 Blanks for tape leader trailer
/	Ignore rest of line
,	Set second limit
{	Echo line on data file
-	Start controller
<	Switch TTY output to data tape output

Notes: (1) Where applicable, the parameter value is entered immediately after the command.

(2) n, m denotes that the setting applies for channel n, where only n is specified, or for channels n to m where both n and m are specified; n and m are in the range 0 to 9 with m $>$ n.

TABLE 2. AUTOCELL OPERATING PROGRAM (ACOP) - CHARACTERS RECOGNISED BY THE INSTRUCTION AND DISPLAY LINE INTERPRETERS

Instruction line interpreter

C	Clear Histogram
D	Type Data Line
E	Type Selected Data
H	Add data to Histogram
L	List I.S. buffer, effective immediately after I only
O	Open I.S. buffer, effective immediately after I only
P	Output Histogram CTRL O, Terminates Histogram printout
W	Wait for 1 delay loop
( )	Round bracket loop
< >	Angle bracket loop
.	Wait for computer delay
,	Start controller program
+	Enter extra data into file
&	Repeat from beginning
#	Type CR LF
%	Insert CR LF on data tape
?	Wait for operator to type ALT mode character CTRL A, Return to command mode
CAR RETURN	Immediately after I, leaves I.S. buffer unchanged
SPACE	Step over, separating character

All other characters echoed, and followed by ?

Display line interpreter

A	Display attenuator finalisation register
B	Display filter outputs
C	Compute and display azimuth elevation angles
E	Display exit
F	Display frequency
G	Display gain finalisation register

TABLE 2(CONTD.).

Display line interpreter

L	List D.S. Buffer, effective immediately after D only
M	Display Histogram totals, Mean, S.D.
N	Display parameter line number
O	Open D.S. Buffer, effective immediately after D only
P	Display phase finalisation register
Q	Display 4 phase outputs
R	Display 2 phase outputs
S	Display 5 phase outputs
T	Display time
U	Display decimal time
V	Display zenith angles
#	Carriage return, line feed
$	Space
.	Write binary format on data type
(	Display only if exit = 0
<	Display only if exit = Non zero
+ +	Display for INS SEQ Extra Data
/	Change Display inhibit
" "	Display text

Characters prior to / are entered into the data file. Characters after / are displayed. Characters after a second use of / are again entered into the data file, and so on. The / character cancels conditional inhibits other than INS. SEQ. E inhibit.

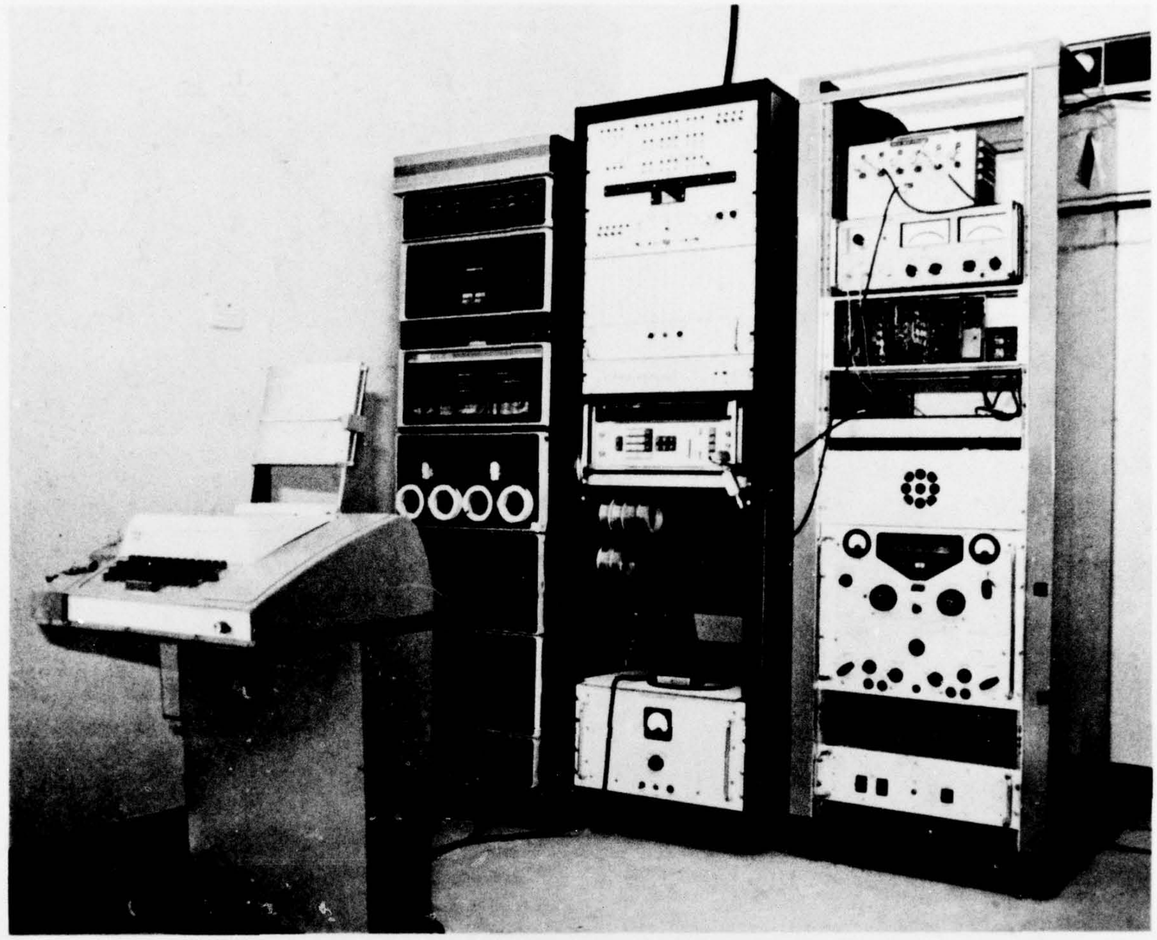
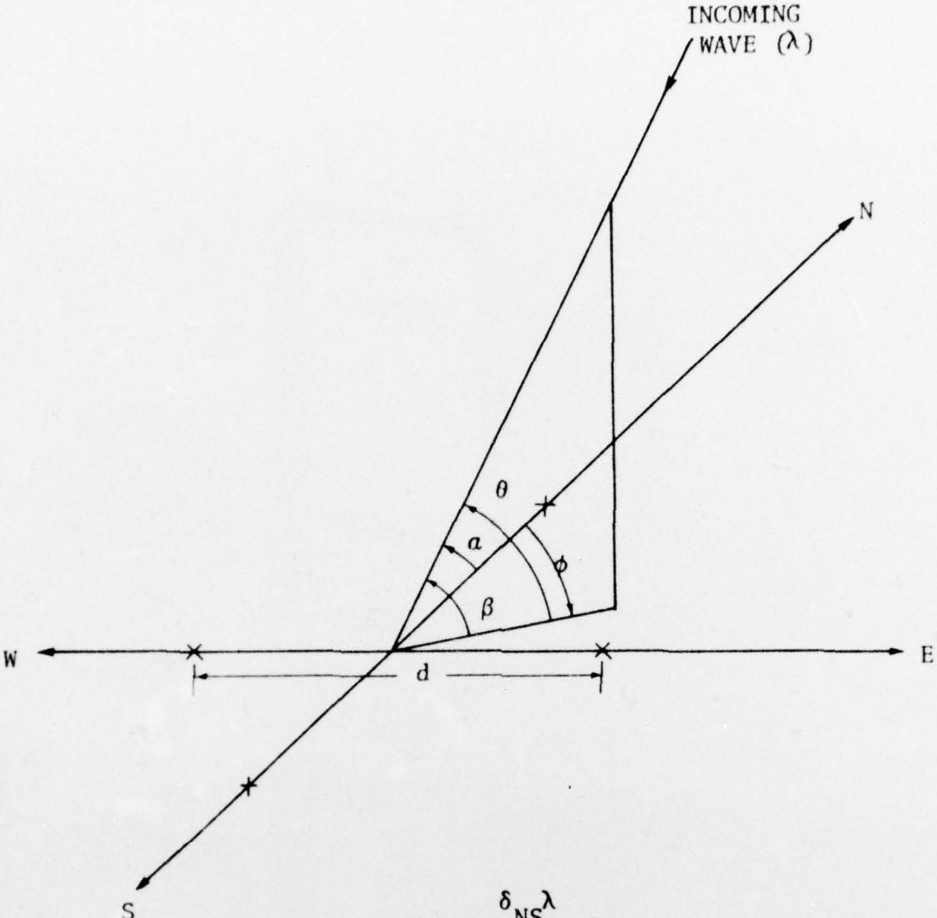


Figure 1. Photograph of autocell equipment



$$\cos a = \frac{\delta_{NS}\lambda}{2\pi d}$$

$$\cos \beta = \frac{\delta_{EW}\lambda}{2\pi d}$$

$$\phi \text{ (bearing)} = \tan^{-1} \frac{\cos \beta}{\cos a}$$

$$\theta \text{ (elevation)} = \cos^{-1} \sqrt{\cos^2 a + \cos^2 \beta}$$

Figure 2. Schematic representation of interferometer and incoming wave

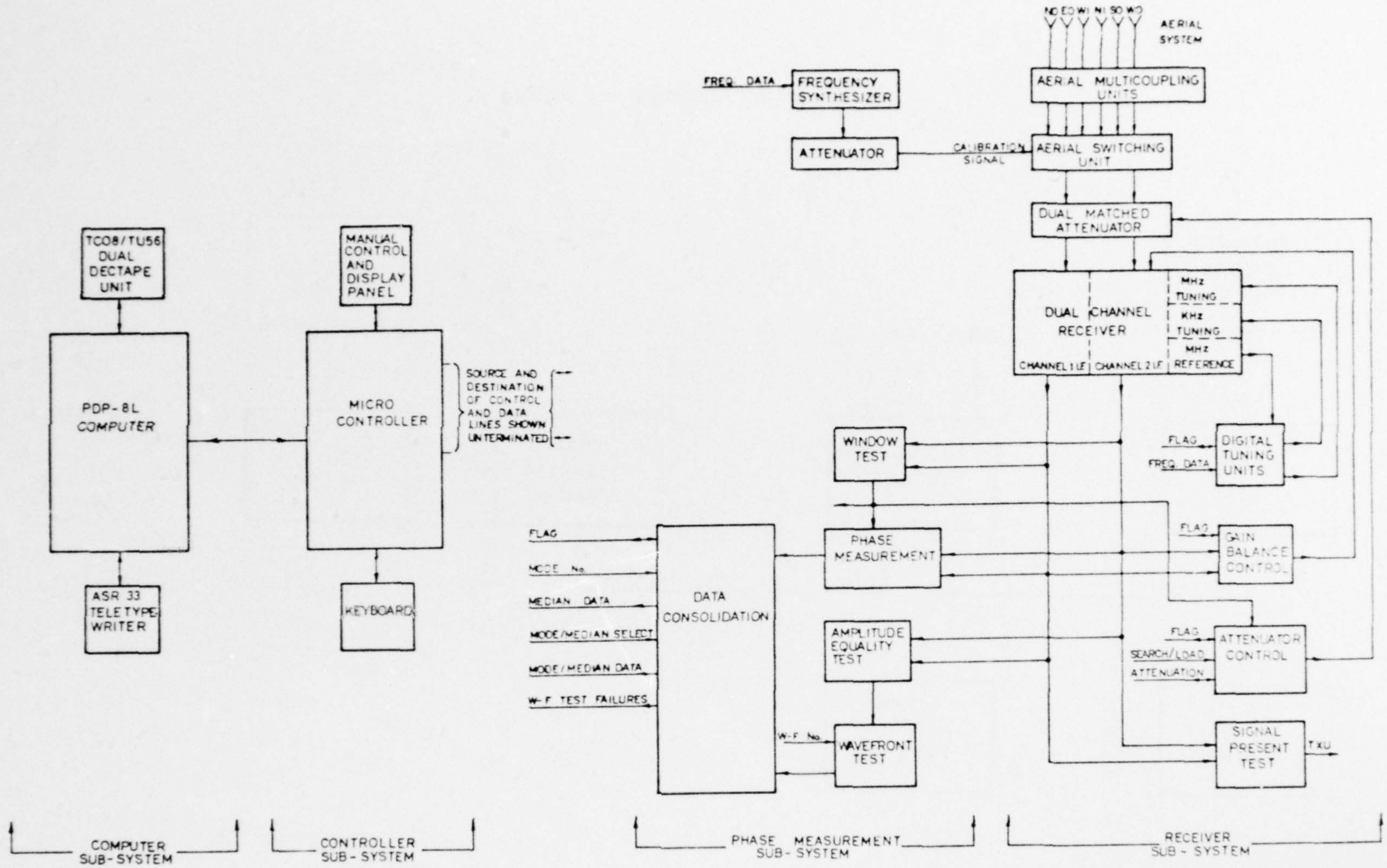


Figure 3. Autocell block schematic

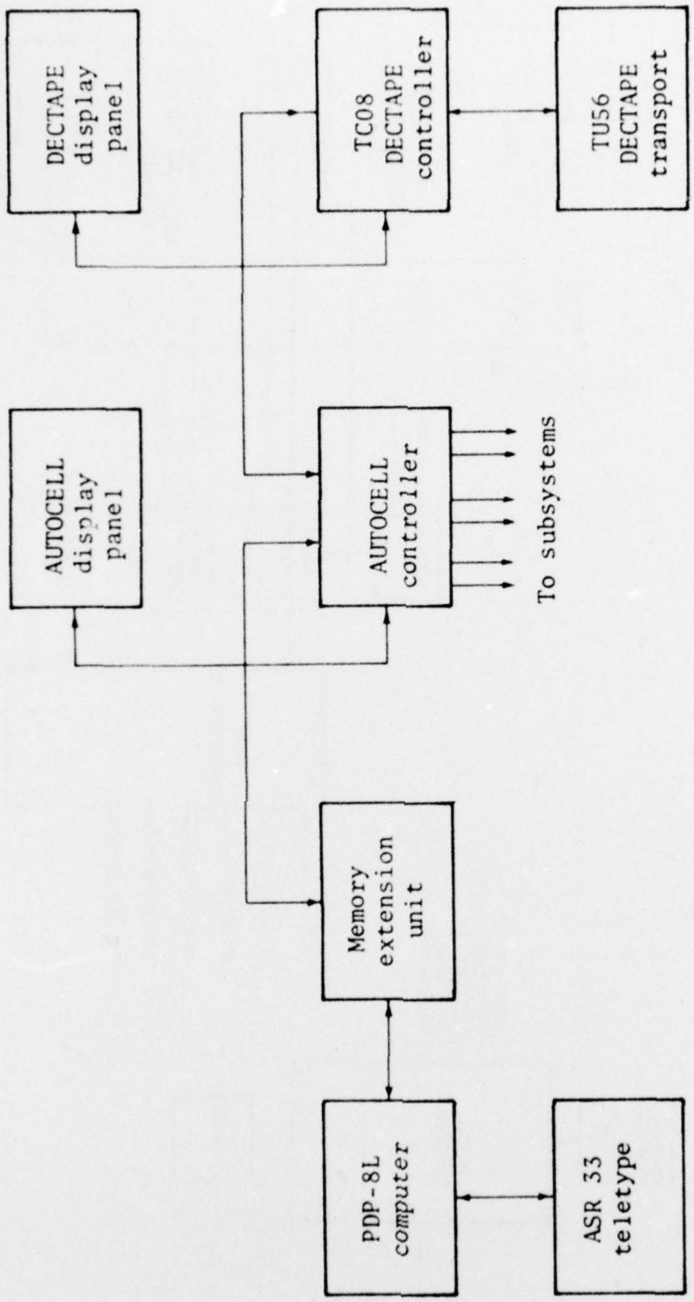


Figure 4. Computer daisy chain

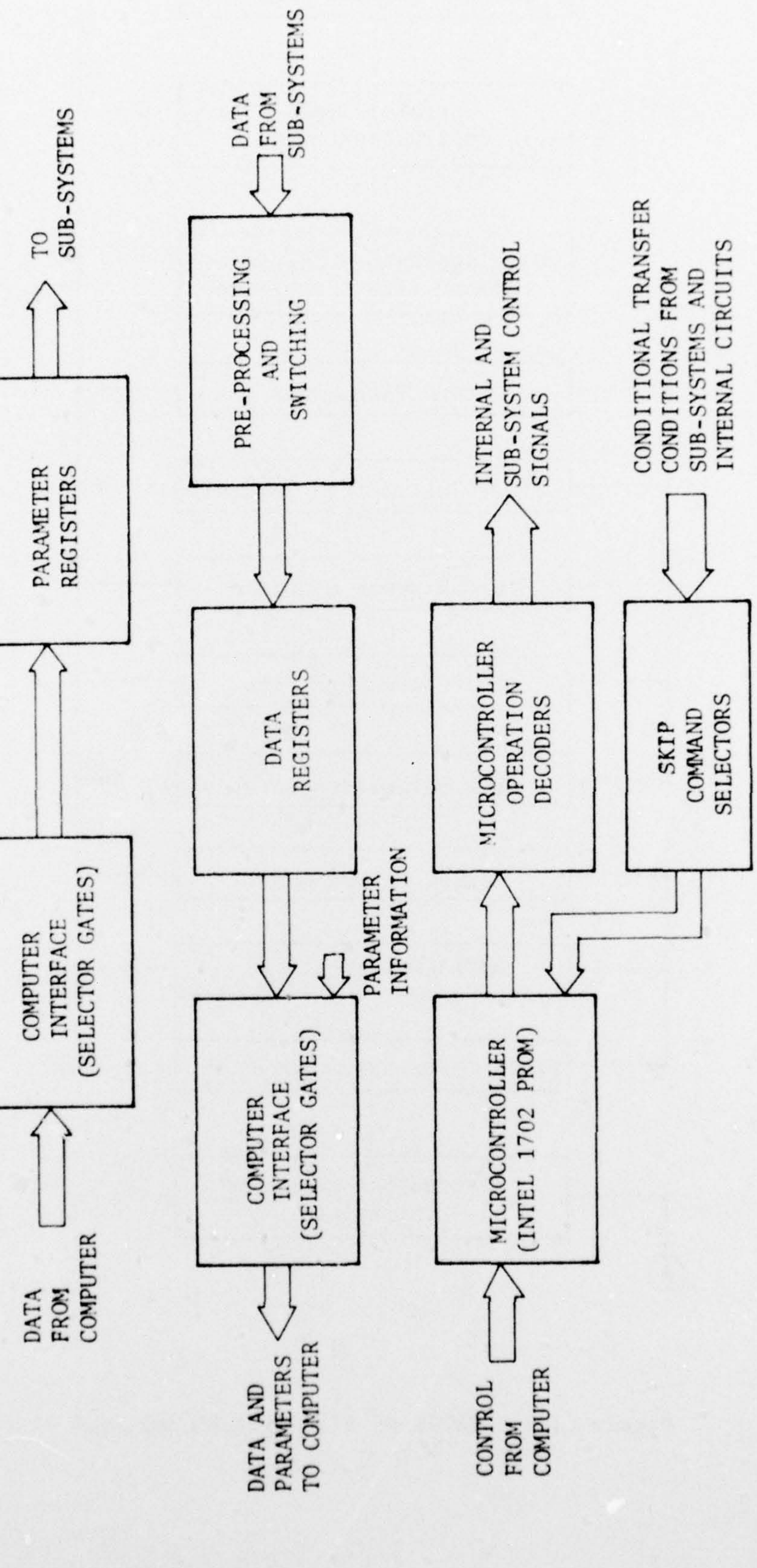


Figure 5. Autocell controller block diagram

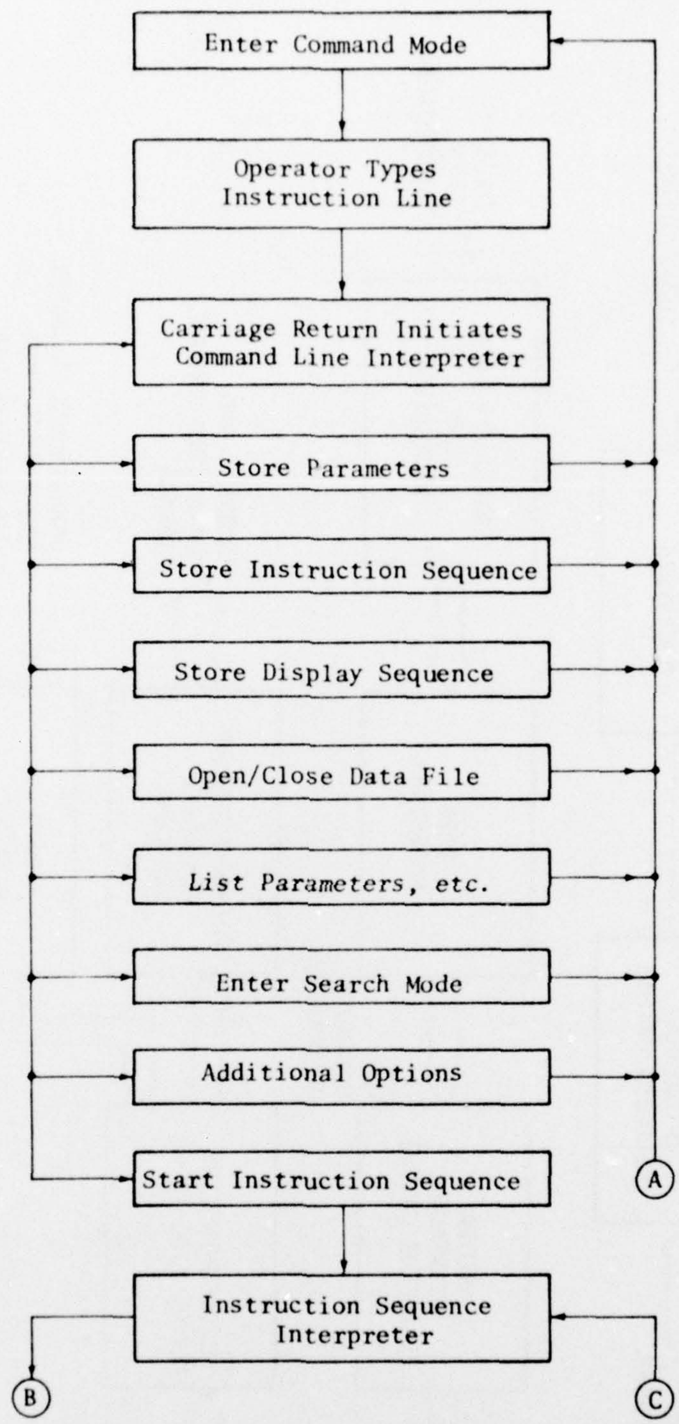


Figure 6(a). Skeleton flow diagram for ACOP

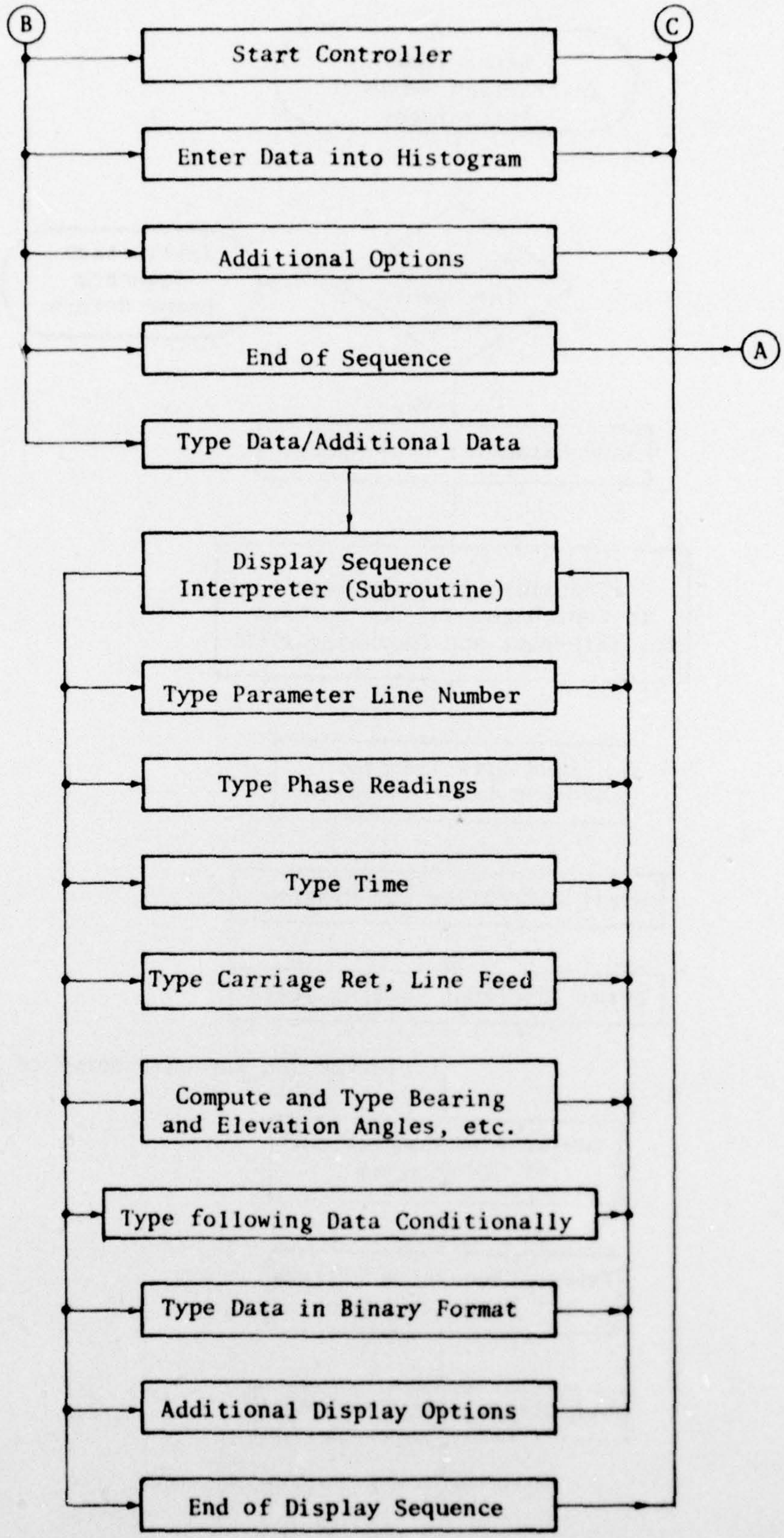


Figure 6(b). Skeleton flow diagram for ACOP

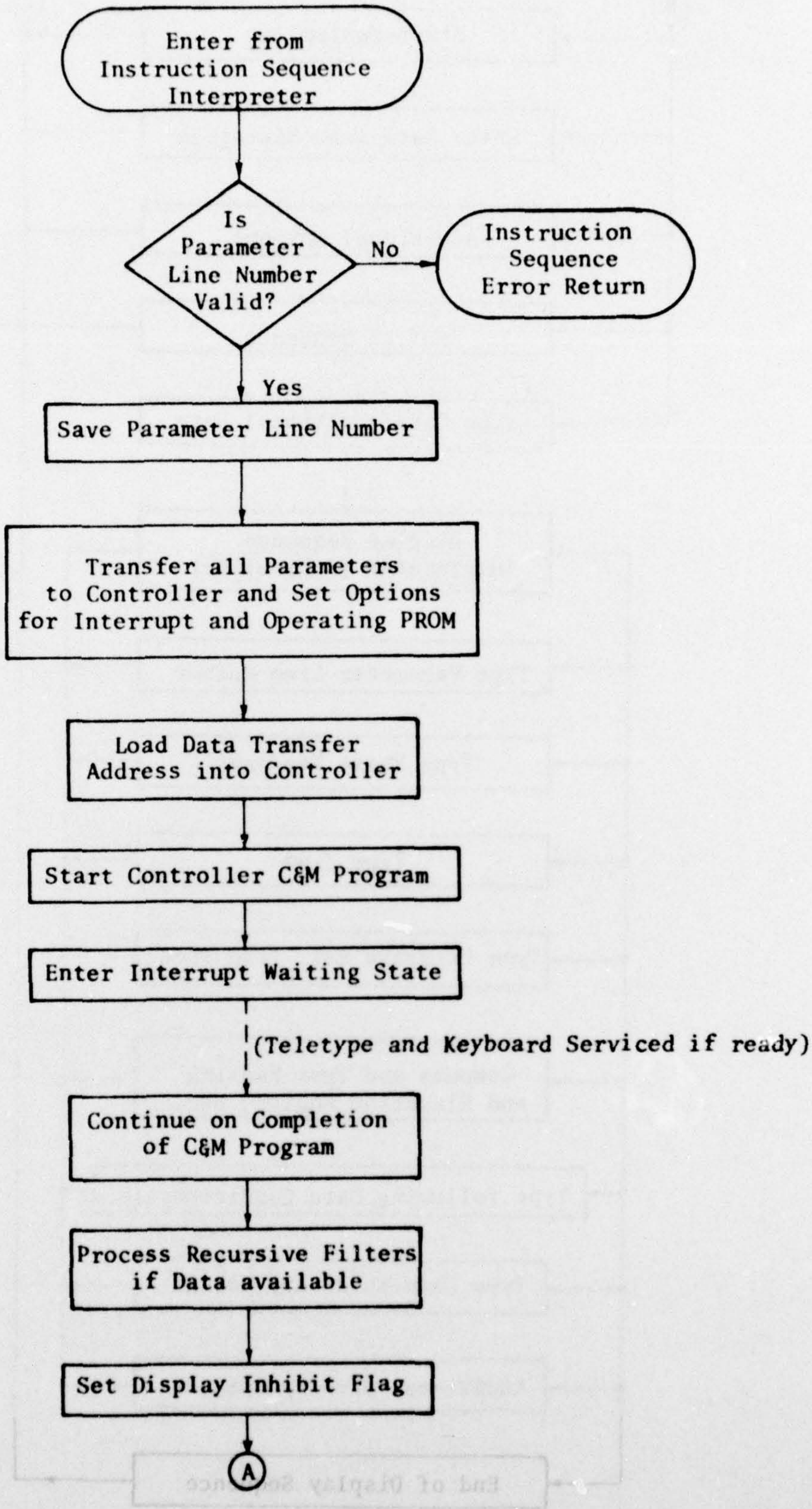


Figure 7(a). Instruction sequence - start controller operation

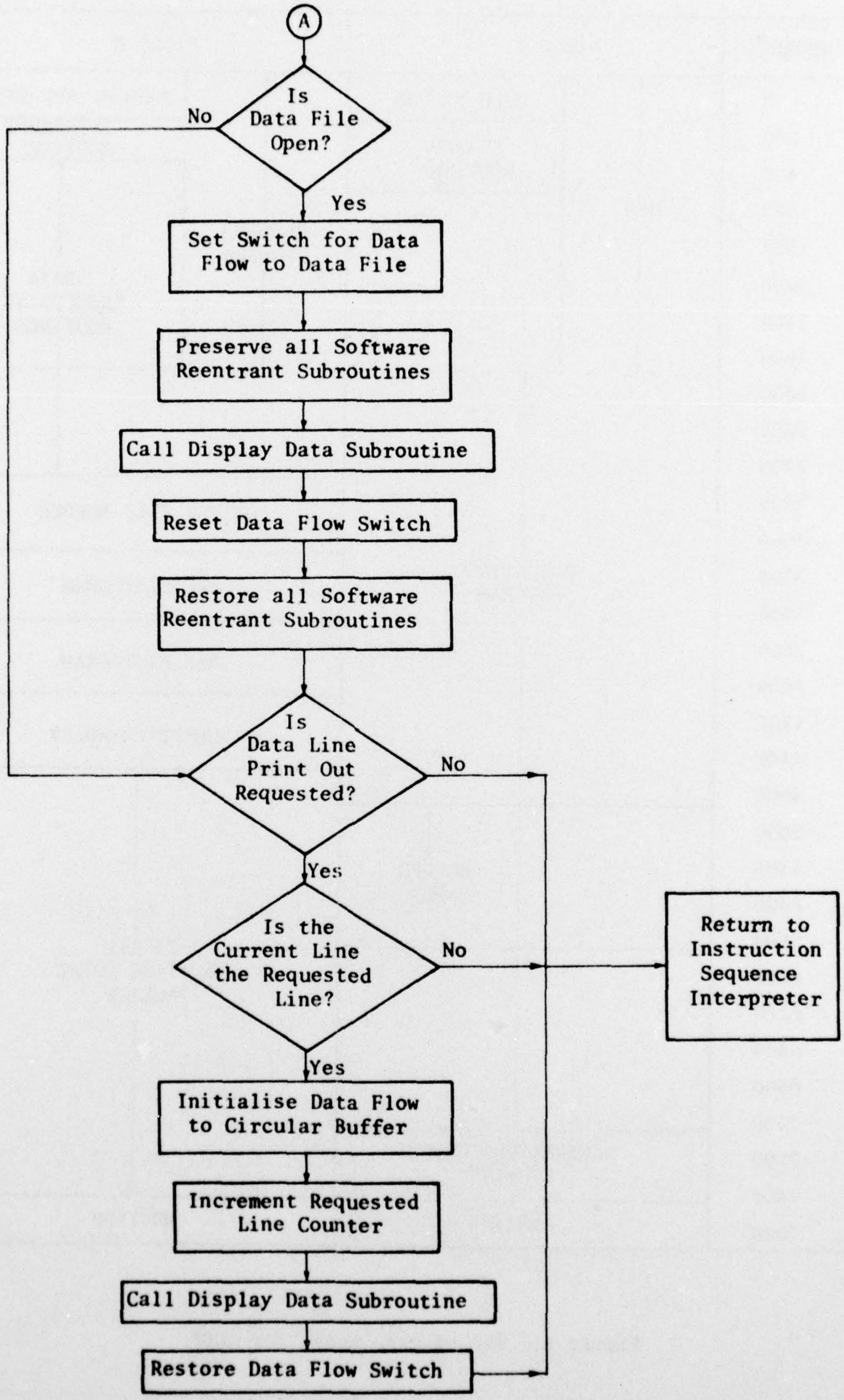


Figure 7(b). Instruction Sequence - Start Controller Operation

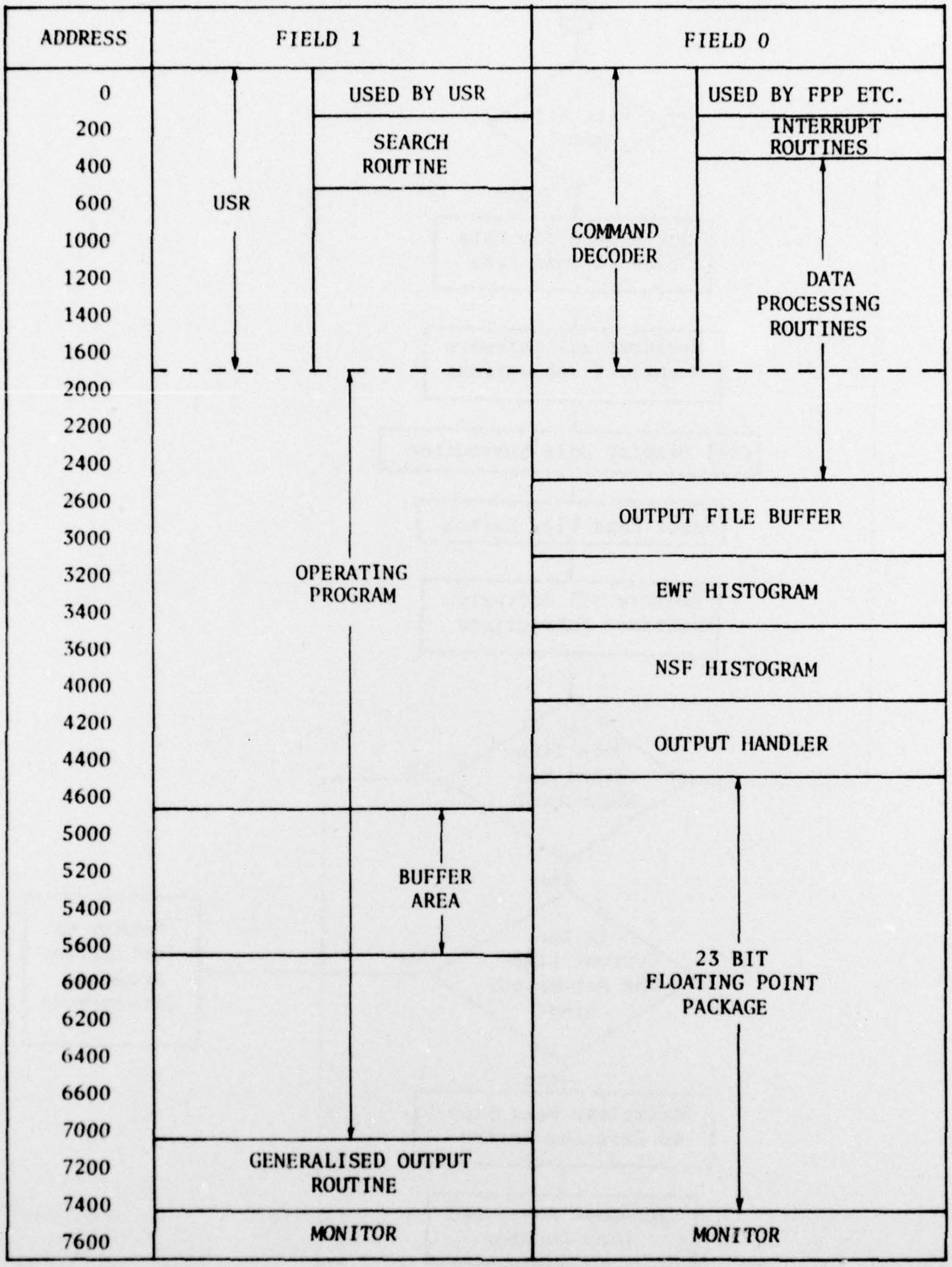


Figure 8. Map of core usage for ACOP

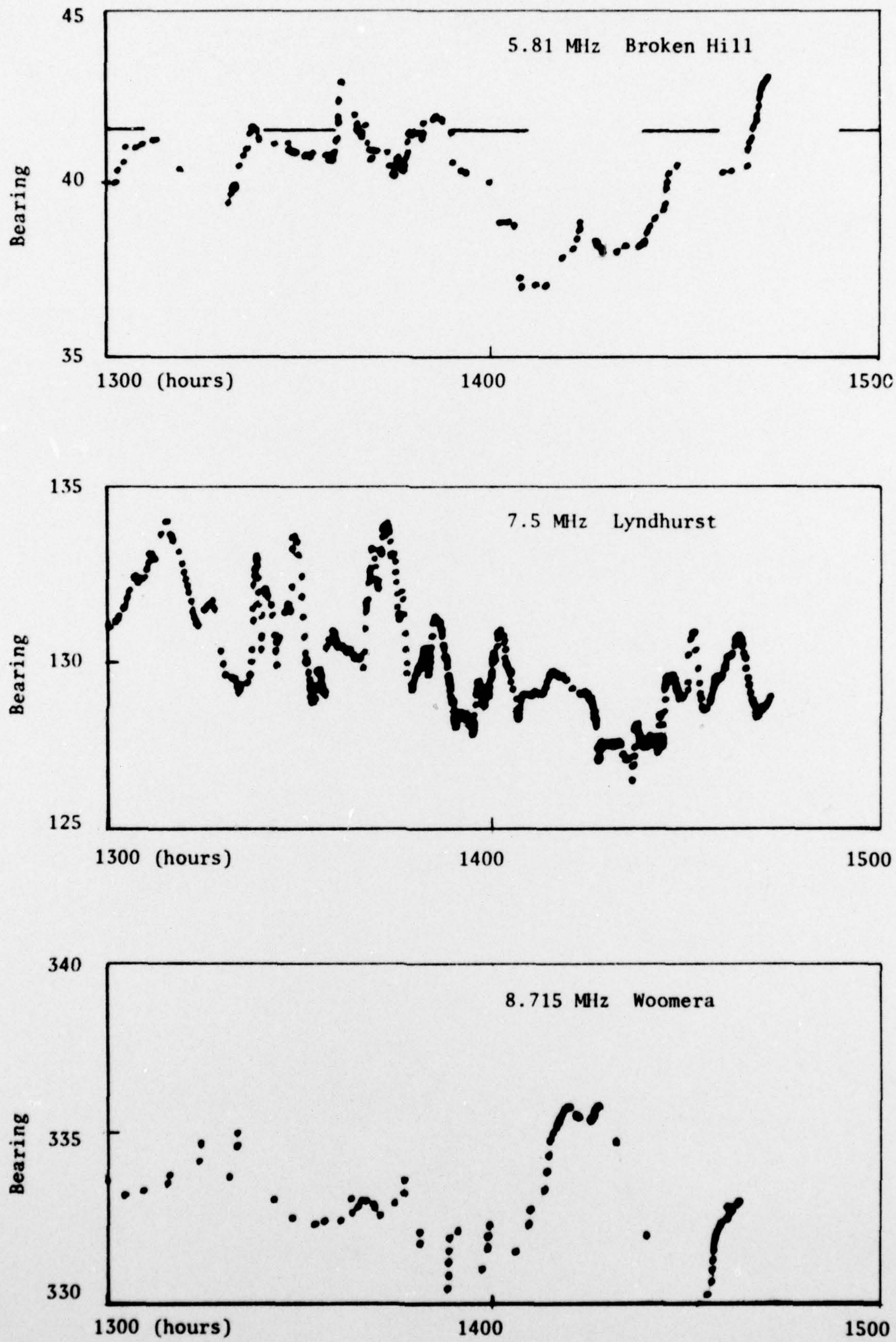


Figure 9. Results from initial trial with Autocell (21-8-75)

DISTRIBUTION

EXTERNAL	Copy No.
Chief Defence Scientist	1
Controller, Military Studies and Operational Analysis Division	2
Superintendent, Military Advisers Branch	3
Army Scientific Adviser	4
Controller, Programme Planning and Policy Division	5 - 6
Head, Defence Science and Technology Planning Branch	7
Executive Controller, Australian Defence Scientific Service	8
Superintendent, Defence Science Administration	9
Director, Defence Signals Division	10
Director, Joint Intelligence Organisation (DDSTI)	11
Assistant Secretary, Ionospheric Prediction Service	12
Defence Library, Campbell Park	13
Library, Aeronautical Research Laboratories	14
Library, Materials Research Laboratories	15
Assistant Secretary, Defence Information Services (for microfilming)	16
Defence Information Services Branch	
United Kingdom, for Ministry of Defence, Defence Research Information Centre	17
United States, for Department of Defense, Defense Documentation Center	18 - 29
Canada, for Ministry of Defence, Defence Science Information Service	30
New Zealand, Ministry of Defence	31
Australian National Library	32

INTERNAL	
Director	33
Chief Superintendent, Applied Physics Wing	34
Superintendent, Communications and Electronic Engineering Division	35
Superintendent, Electronics Division	36
Superintendent, Systems Analysis Division	37
Senior Principal Research Scientist, Electronic Warfare	38
Principal Officer, Cybernetic Electronics Group	39
Principal Officer, Ionospheric Studies Group	40
Principal Officer, Radar and Electronic Tracking Group	41
Principal Officer, Radio Group	42
Principal Officer, Telecommunications Group	43
Principal Officer, Tropospheric Studies Group	44

	Copy No.
Principal Engineer, Communications	45
Mr R.L. Farrell, Cybernetic Electronics Group	46
Mr G.E. Moore, Cybernetic Electronics Group	47
Mr N.J. Steer, Cybernetic Electronics Group	48
Mr W.A. Eason, Ionospheric Studies Group	49
Mr R.M. Ellard, Ionospheric Studies Group	50
Mr D.N. Warren-Smith, Jindalee Project Group	51
Mr Z.R. Jeffrey, Tropospheric Studies Group	52
Mr M.L.J. Raymond, Tropospheric Studies Group	53
Group Clerk, Tropospheric Studies Group	54 - 73
Library, W.R.E.	74 - 75
Spares	76 - 82