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A Short Report on Voltage-to-Frequency Conversion for HISTRAP RF System Tuning Control Loops

A. M. Hasanul Basher

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Physics Division

A SHORT REPORT ON VOLTAGE-TO-FREQUENCY CONVERSION FOR HISTRAP RF SYSTEM TUNING CONTROL LOOPS

A. M. Hasanul Basher

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A SHORT REPORT ON

VOLTAGE-TO-FREQUENCY CONVERSION

FOR

HISTRAP RF SYSTEM TUNING CONTROL LOOPS*

A. M. Hasanul Basher[1]
Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6368

August 17, 1990

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1 Summer Faculty Research Participant, School of Engineering Technology, South Carolina State College, Orangeburg, South Carolina 29117.

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INTRODUCTION

One of the requirements of the HISTRAP RF accelerating system is that the frequency of the accelerating voltage for the cavity must keep in step with the change in the magnetic field. As the energy of the particle increases, the magnetic field is increased to keep the radius of the particle orbit constant. At the same time, the frequency of the electric field must be changed to insure that it is synchronized with the angular movement of the particle. So we need to generate the frequency of the accelerating voltage in relation to the magnetic field.

The frequency generation can be accomplished in two stages. The first stage of frequency generation consists of measuring the magnetic field in terms of voltage which is already developed. The second stage is to convert this voltage into frequency. Final frequency precision can be achieved by deriving a frequency-correcting signal from the beam position.

This project is concerned with generating the frequency from the analog voltage. The speed of response required will place very stringent requirements on both hardware and software. Technology is available to carry out this task. A hardware configuration has been established and software has been developed.

In the following sections, we describe the implementation strategy, the hardware configuration, and the desired specifications. Next, we present the software developed, results obtained, along with capabilities and limitations of the system. Finally, we suggest alternate solutions to overcome some of the limitations toward meeting our goal. In the appendices, we include program listings.

IMPLEMENTATION STRATEGY

The implementation of frequency generation from voltage will be carried out in three steps shown below:

1. Convert the analog signal (voltage) into digital signal.

2. Compute the frequency value that corresponds to the digital signal.

3. Generate the signal taking frequency value computed in step 2.

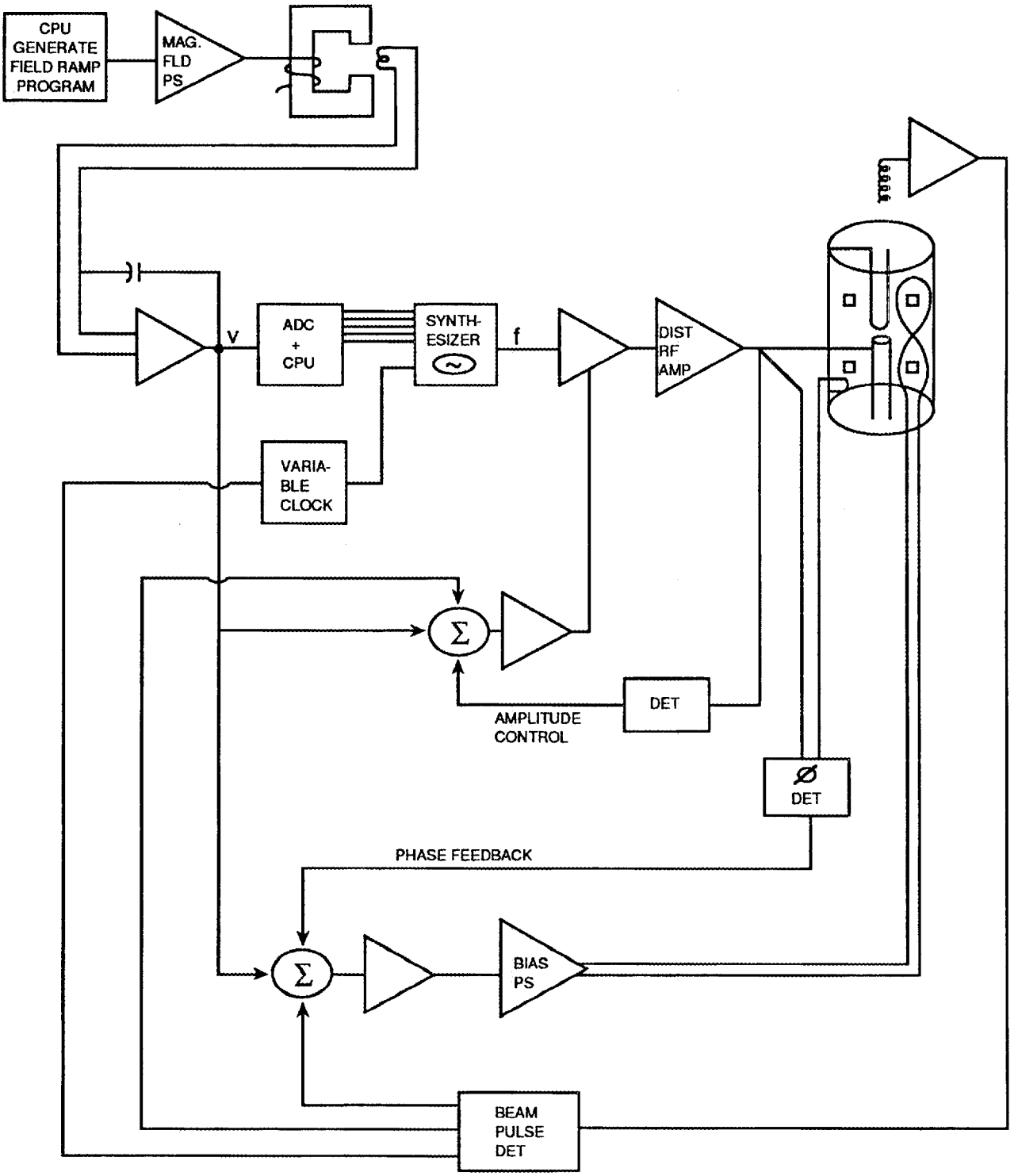
Conversion of analog voltage to digital can be done with the help of an analog-to-digital converter. A high sampling rate is desirable for the precise measurement of the instantaneous value of the analog input.

CPU will be used for the frequency value computation.

A frequency synthesizer capable of generating glitch-free signal and having reasonably fast switching characteristics over the desired frequency range will be utilized to accomplish the third step above.

A software program will be written to aid the CPU communicating with the analog-to-digital converter and the frequency synthesizer. In developing the software, care must be taken so the execution time can be kept at a minimum.

HISTRAP RF SYSTEM TUNING CONTROL LOOPS



HARDWARE CONFIGURATION

Hardware

a. Analog-to-Digital Converter

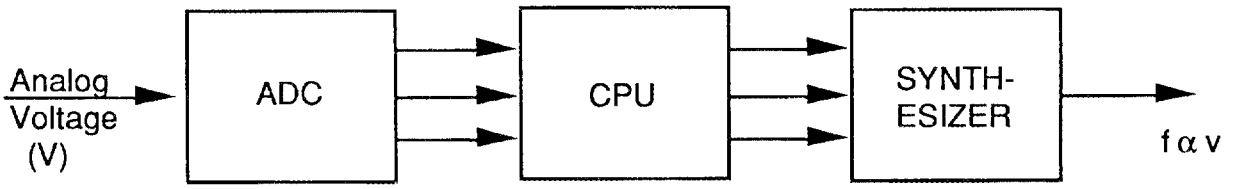
DT2814
12-bit resolution
25 μs A/D conversion time

b. CPU

IBM-PC or compatible

c. Frequency synthesizer

HP 3325A



Software

Written in Assembly language

SPECIFICATIONS

1.	Frequency range	–	0.2 to 2.7 MHz
2.	Sampling interval	–	10 μs
3.	$\frac{\Delta f}{f}$	–	$< 2 \times 10^{-4}$

1. Frequency range can be achieved without much difficulty.
2. This small sampling interval places very strict requirements on both hardware and software.
3. Frequency precision can be achieved by a correcting signal taken from the beam.

FLOWCHARTS

This section includes the flowcharts of the programs written, as well as initialization procedure for interrupt. Important segments of the program are also explained in detail. It covers the following:

1. Voltage-to-frequency conversion

   Without interrupt
   On interrupt basis

2. Look-up table generation

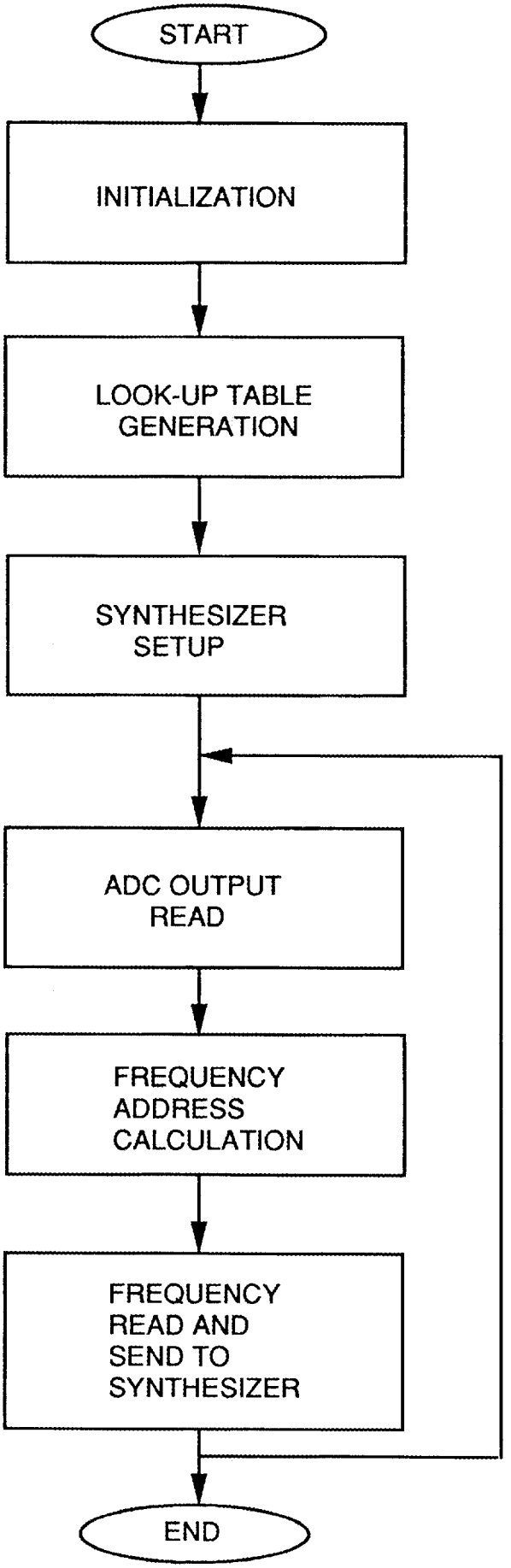
3. Frequency address calculation

4. ADC output read

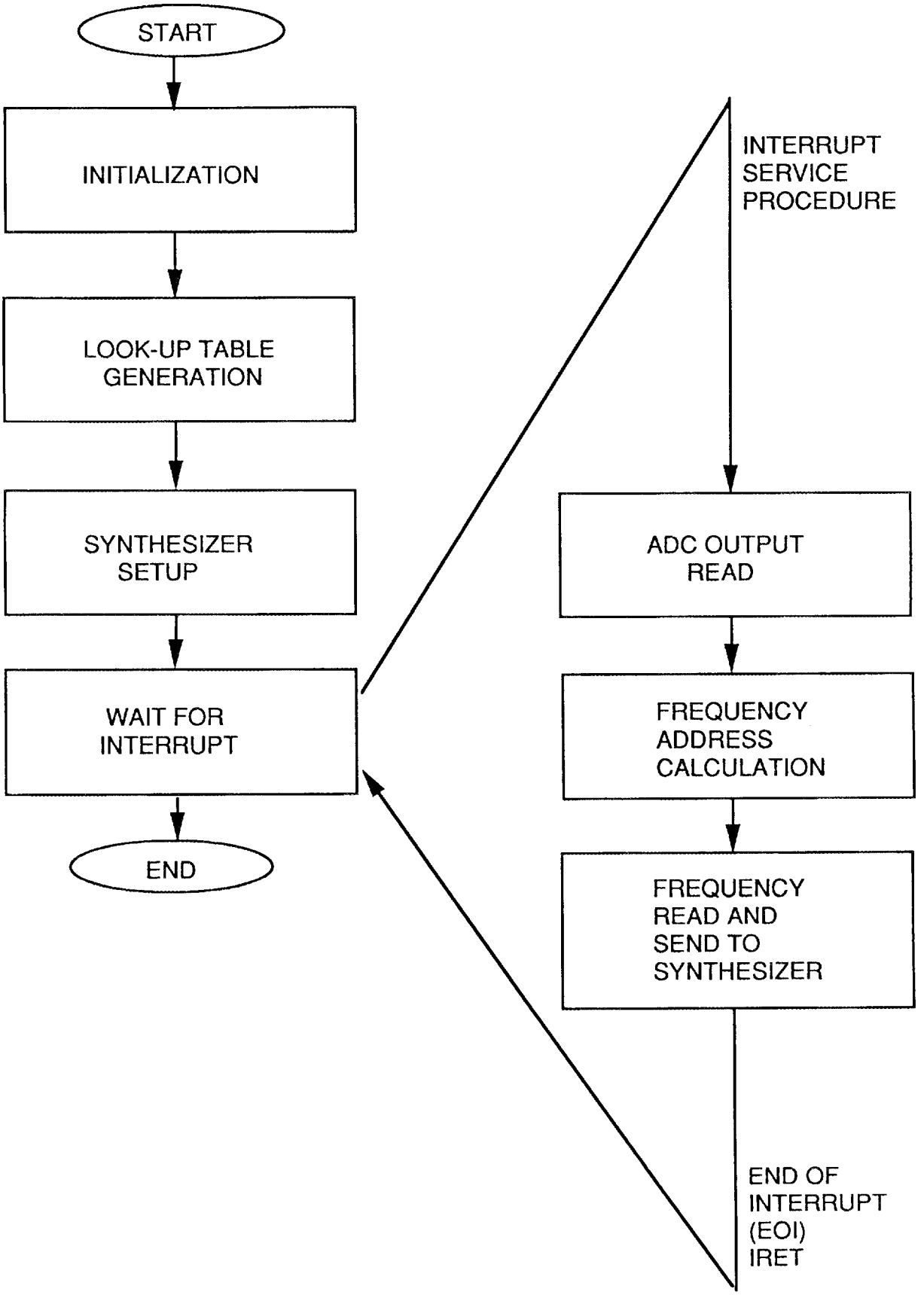
5. Initialization for interrupts

6. Some program segments

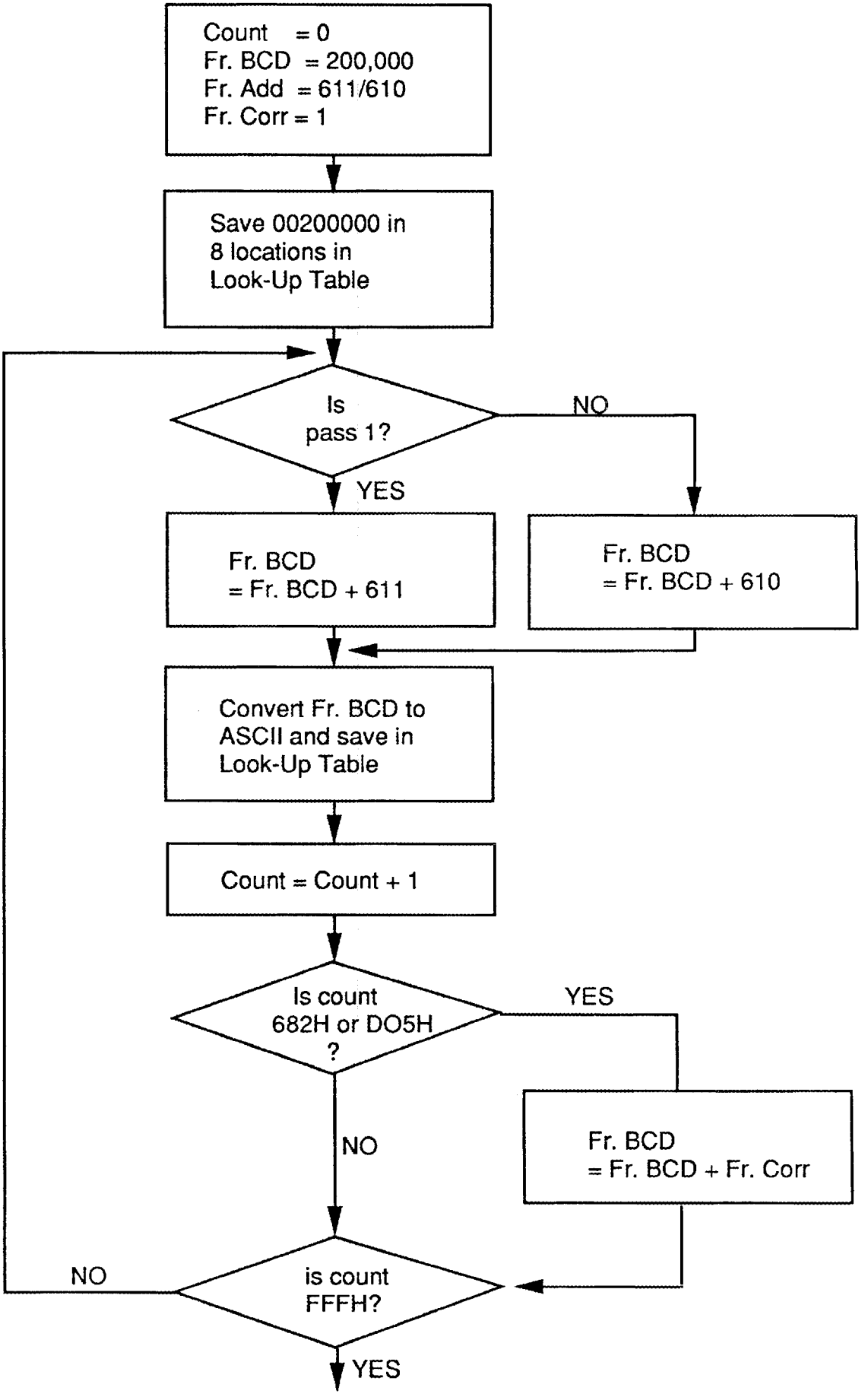
VOLTAGE-TO-FREQUENCY CONVERSION



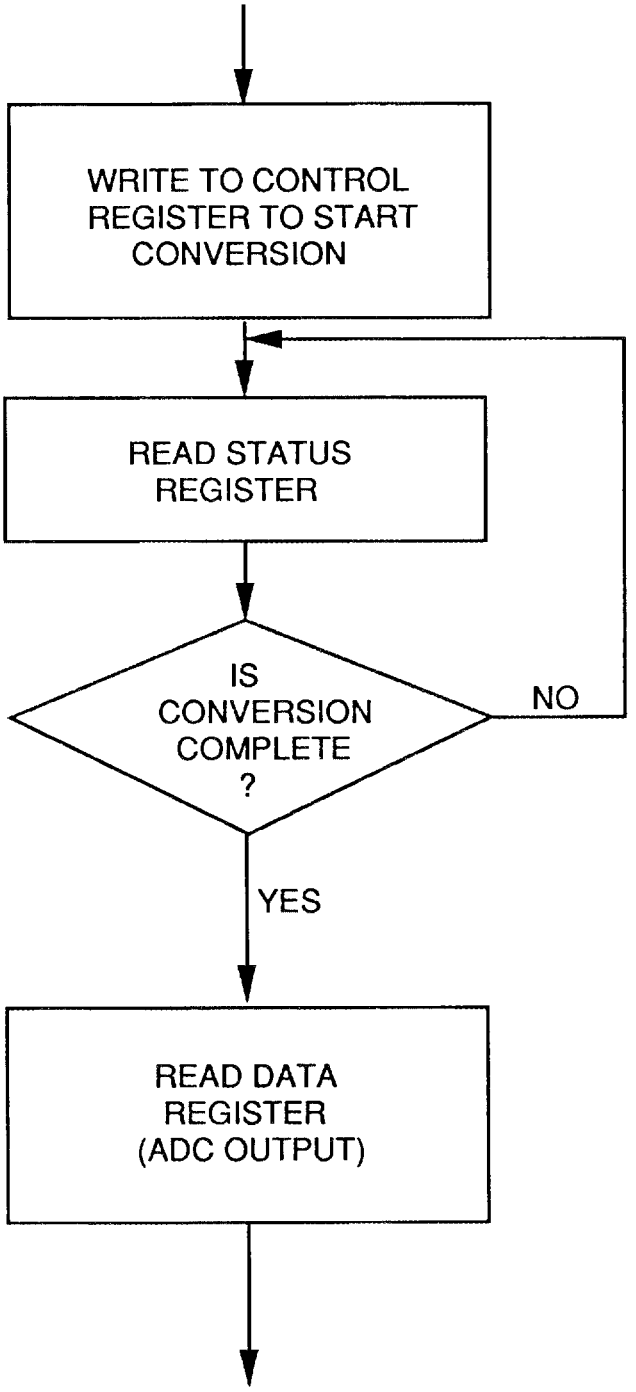
VOLTAGE-TO-FREQUENCY CONVERSION
ON INTERRUPT BASIS



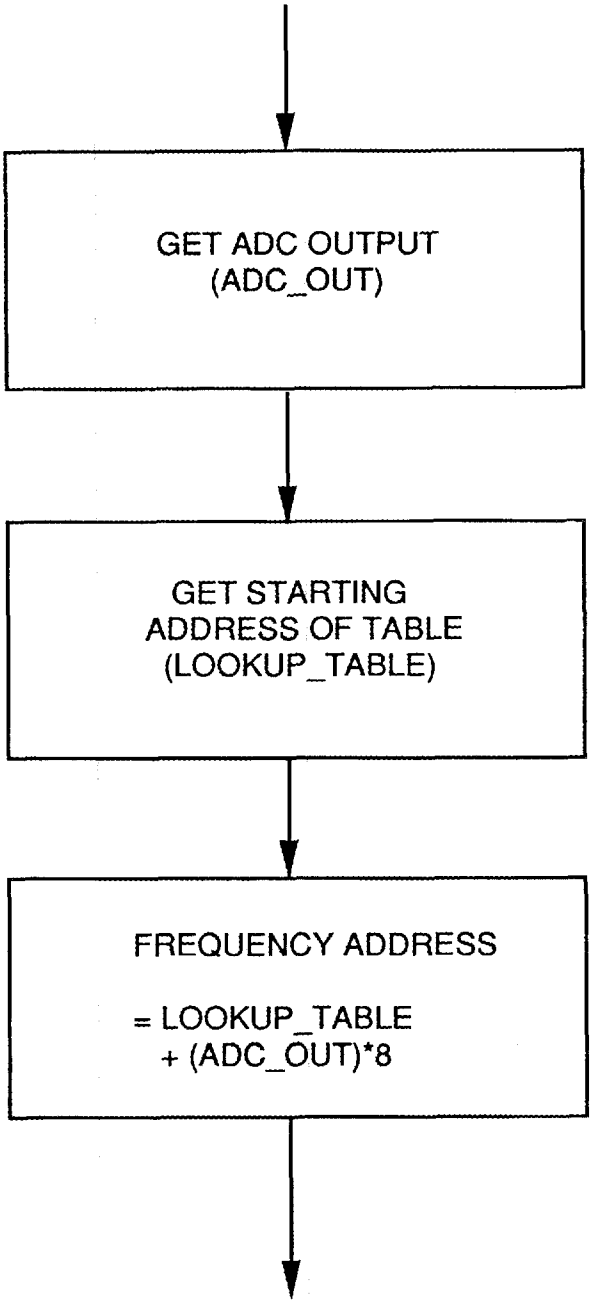
LOOK-UP TABLE GENERATION



ADC OUTPUT READ



FREQUENCY ADDRESS CALCULATION



PROGRAM SEGMENT

Section to be executed continuously

```
;
;   ADC output read with analog signal connected to channel Ø
;
START:
        MOV DX,Ø22ØH                ;  point at control register
        MOV AL,ØØ                   ;  select channel Ø
        OUT DX,AL                   ;  send control word
WAIT:   IN AL,DX                    ;  read status register and wait
        CMP AL,8ØH                  ;  until conversion is complete
        JB  WAIT                    ;  read if not complete
        INC DX                      ;  point at data register
        IN AL,DX                    ;  read data register, MSB
        MOV AH,AL
        IN AL,DX                    ;  read data register, LSB
        SHR AX,1                    ;  "to reduce execution time AX is
        SHR AX,1                    ;  shifted 4 times instead of
        SHR AX,1                    ;  doing in one instruction
        SHR AX,1                    ;  using CL"
        MOV BX,AX                   ;  save ADC output in BX
;
;   calculate frequency address from lookup table for
;   the ADC output read above
;
        LEA SI,LOOKUP_TABLE         ;  point to beginning of table
        SHL BX,1                    ;  generate offset of frequency
        SHL BX,1                    ;  by multiplying ADC output
        SHL BX,1                    ;  with 8, then sum with SI
        ADD SI,BX                   ;  to get the address
;
;   Frequency value sent to synthesizer, Model HP3325A.
;
        MOV DX,1                    ;  select printer
        MOV CX,SYN_CHAR_2           ;  no. of characters to send
AGAIN:  MOV AH,Ø                    ;  print character
        MOV AL,[SI+7]               ;  get character in AL
        INT 17H                     ;  BIOS call for print
        DEC SI                      ;  point to next character
        LOOP AGAIN                  ;  if more, continue
;
;   frequency unit sent to synthesizer, Model HP3325A
;
        LEA BX,FREQ_UNIT            ;  point at frequency unit
        MOV CX,SYN_CHAR_3           ;  no. of characters to send
   FZ1: MOV AH,Ø                    ;  print character
        MOV AL,[BX]                 ;  get character in AL
        INT 17H                     ;  BIOS call for print
        INC BX                      ;  point to next character
        LOOP FZ1                    ;  if more, continue
;
```

INTERRUPT

A. INTERRUPT ROUTINE ADDRESS – Place in INTR. VECT. Table

B. INITIALIZE INTERRUPT CONTROLLER

1. Control word and data port addresses

2. Control word and data word

a.	Trigger-type (edge/level	C	ICW1
b.	Single or cascade	C	ICW1
c.	Type of interrupt	D	ICW2
d.	Slave code (cascade)	D	ICW3
e.	Mode selection	D	ICW4
f.	Unmask interrupt	D	OCW1

* ICW – Initialization command word
OCW – Operation command word

C. INITIALIZE COUNTER/TIMER

1. Control register and counter addresses

2. Counter clock frequency

3. Control word and counter word

a.	Select counter	C
b.	Read/write option	C
c.	Mode selection (out of 5)	C
d.	Count type (binary/BCD)	C
e.	Load counter with count	D

INTERRUPT INTERVAL

Depends on counter clock frequency.

For a clock frequency of 1.190 MHz, the range of interrupt interval is:

0.8 μs – 55.1 ms

Counter loaded with OFFFFH gives interval of 55.1 ms.

PROGRAM SEGMENT

INITIALIZATION FOR INTERRUPT

```
;
;   define address of interrupt service
;   procedure, interrupt type 64
;
        MOV AX,ØØØØH
        MOV ES,AX
        MOV WORD PTR ES:Ø1Ø2H, SEG ADC_FREQ_PROC
        MOV WORD PTR ES:Ø1ØØH, OFFSET ADC_FREQ_PROC
;
;   initialize interrupt controller
;
        MOV AL,11H              ;   edge-triggered, cascade, ICW4
        MOV DX,2ØH              ;   point at 8259 control
        OUT DX,AL               ;   send ICW1
        MOV AL,4ØH              ;   type 64 interrupt
        MOV DX,21H              ;   point at ICW2 address
        OUT DX,AL               ;   send ICW2
        MOV AL,Ø4H              ;   slave code
        OUT DX,AL               ;   send slave code
        MOV AL,Ø1H              ;   ICW4, 8Ø86 mode
        OUT DX,AL               ;   send ICW4
        MOV AL,ØFEH             ;   OCW1 to unmask IRØ
        OUT DX,AL               ;   send OCW1
;
;   initialize counter/timer for 1 kHz output
;   command word for counter Ø,LSB then MSB,square wave,BCD
;
        MOV AL,37H              ;   8254 control word
        MOV DX,43H              ;   point at control address
        OUT DX,AL               ;   send control word
        MOV AL,58H              ;   load LSB of count
        MOV DX, 4ØH             ;   point at counter Ø addr.
        OUT DX,AL               ;   send LSB of count
        MOV AL,24H              ;   load MSB of count
        OUT DX,AL               ;   send MSB of count
```

RESULTS: EXECUTION TIME

EXECUTION TIME

(10 MHz CPU)

The sampling interval of 10 μs cannot be achieved unless the program segments such as ADC OUTPUT READ, FREQUENCY ADDRESS CALCULATION and FREQUENCY SEND TO SYNTHESIZER are executed during 10 μs interval. The execution time depends equally on hardware and software. The following table shows our results in terms of the execution times of the three program segments mentioned above. The following pages contain the information regarding the machine cycles of these program segments.

Program Segment	Execution Time
ADC OUTPUT READ	
Including conversion time	35 μs
Excluding conversion time	5.2 μs
FREQUENCY ADDRESS CALCULATION	2 μs
FREQUENCY SEND TO SYNTHESIZER	36 ms

The high execution times, such as 35 μs and 36 ms, are mainly because of hardware being used. Also, we must note that the execution times are true for 10 MHz CPU. Even if we use higher speed CPU, still the ADC and the synthesizer we utilized here will not allow us to achieve the desired sampling rate. The next few pages will reveal how the hardware does slow down the process.

EXECUTION TIME

(For 10 MHz CPU)

MODULE: ADC OUTPUT READ

Execution time	–	35 µs
Execution time without the bracketed portion	–	5.2 µs

COMMENT: The execution time of the bracketed portion depends on the conversion time of the ADC.

Execution time is measured by executing the section of the program 1,000,000 times.

```
;
; ADC output read >                    Machine Cycles
;
START:
        MOV DX,0220H                        4
        MOV AL,00                           4
        OUT DX,AL                          10
WAIT:   IN AL,DX
        CMP AL,80H
        JB  WAIT
        INC DX                              2
        IN AL,DX                           10
        MOV AH,AL                           2
        IN AL,DX                           10
        SHR AX,1                            2
        SHR AX,1                            2
        SHR AX,1                            2
        SHR AX,1                            2
        MOV BX,AX                           2
                                           ---
                                            52
```

Total number of machine cycles – 52
(Without marked portion)

EXECUTION TIME

(10 MHz CPU)

MODULE: FREQUENCY ADDRESS CALCULATION

Execution time – 2 µs

COMMENT: Execution time was measured by executing this section 1,000,000 times.

Hand-calculated machine cycles are shown below.

```
;
; calculate frequency address
; the ADC output read above                Machine Cycles
;
        LEA SI,LOOKUP_TABLE                 7
        SHL BX,1                            2
        SHL BX,1                            2
        SHL BX,1                            2
        ADD SI,BX                           3
;                                          ----
                                            16
```

Total number of machine cycles – 16.

EXECUTION TIME

MODULE: FREQUENCY SEND TO SYNTHESIZER

Execution time – 36 ms

COMMENT: Execution time for this section of the program was so high mainly because of large response time of the synthesizer.

```
;
; Frequency value sent to synthesizer
;
        MOV DX,1
        MOV CX,SYN_CHAR_2
AGAIN:  MOV AH,Ø
        MOV AL,[SI+7]
        INT 17H
        DEC SI
        LOOP AGAIN

;
; frequency unit sent to synthesizer
;
        LEA BX,FREQ_UNIT
        MOV CX,SYN_CHAR_3
FZ1:    MOV AH,Ø
        MOV AL,[BX]
        INT 17H
        INC BX
        LOOP FZ1
;
```

HP3325A response time:

Device time	–	2.8 ms/digit
Data transfer time	–	250 µs/digit
Device time for unit	–	12.5 ms

For 8 digits for frequency and unit

Total time = (2.8 + 0.25) x 8 + 12.5 = 36.9 ms

SOLUTION: MEETING THE REQUIREMENTS

From the previous discussion and our results, it seems obvious that in order to meet our requirements we need to change the hardware. With the application of high-speed A/D converter and frequency synthesizer, the execution time can be dramatically decreased. There is also room for reducing the execution time in software. All these are explained in this section.

EXECUTION TIME REDUCTION SCHEME

MODULE: ADC OUTPUT READ

Use a high-speed A/D converter

Possible choice:

DT2831-G (Data Translation, Inc.)

12-bit resolution
16 input channel
* 2 μs conversion time
250 KHz A/D throughput

100 MΩ	Input Impedance (off/on channel)
100 PF	Input Impedance (off/on channel)
0–10 V	Input range

EXECUTION TIME REDUCTION SCHEME

MODULE: FREQUENCY SEND TO SYNTHESIZER

HARDWARE: Use a high-speed synthesizer

Possible choice:

VDS-15 (Citeq Electronics, Inc.)

DC-16 MHz Frequency range
Remote Control
BCD Parallel - Input (38 bits)
≤ 500 ns - Switching Speed
PC Board

SOFTWARE: Use DOS function call instead of BIOS call.

DOS function call allows to send an entire string, rather than just a single character at a time as the BIOS INT 17H does.

DOS FUNCTION CALL IMPLEMENTATION

1. Load function No. 40H into AH register.
2. Load the DS register with the segment base.
3. Load the DX register with the offset of the string.
4. Load the CX register with the number of bytes to write.
5. Load the BX register with the file handle for the printer, 0004H.
6. Execute INT 21H.

* Create look-up table with unit.

EXPECTED EXECUTION TIME – 4-5 μs (10 MHz CPU)

With the implementation of the proposed execution time reduction scheme, it will be possible to bring down the execution time of the segment of the program that is in continuous loop to within 15 μs for a 10-MHz CPU. Then further, if we use a reasonably higher speed CPU, the execution time can be kept below 10 μs. Then we can take samples of analog voltage every 10 μs.

APPENDIX A

PROGRAM LISTINGS

	Filename	Description
1.	VOLT_FR1.ASM	No interrupt, can be run in a continuous loop, look-up table is generated in ASCII.
2.	VOLT_FR2.ASM	Runs on interrupt basis, look-up table is generated in ASCII.
3.	VOLT_FR3.ASM	No interrupt, can be run in a continuous loop, look-up table is generated in BCD (BCD is required by Citeq Synthesizer)

APPENDIX B

Special Notes:

Three different programs are developed and the listings of these are attached to this report. These programs are also in the computer and on the diskette. The filenames and their functions are as follows:

Filename		Function	Directory
VOLT_FR1.ASM	a. b.	No interrupt Look-up table in ASCII	DOS
VOLT_FR2.ASM	a. b.	With interrupt Look-up table in ASCII	DOS
VOLT_FR3.ASM	a. b.	No interrupt Look-up table in BCD	DOS

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